The Impact of Reducing Greenhouse Gas Emissions in Crop Agriculture: A Spatial- and Production-Level Analysis

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With the Waxman-Markey Bill passing the House and the administration's push to reduce carbon emissions, the likelihood of the implementation of some form of a carbon emissions policy is increasing. This study estimates the greenhouse gas (GHG) emissions of the six largest row crops produced in Arkansas using 57 different production practices predominantly used and documented by the University of Arkansas Cooperative Extension Service. From these GHG emission estimates, a baseline state "carbon footprint" was estimated and a hypothetical GHG emissions reduction of 5, 10, and 20 percent was levied on Arkansas agriculture using a cap-and-trade method. Using current production technology and traditional land use choices, results show that the trading of carbon-emitting permits to reduce statewide GHG emissions by 5 percent from the baseline would enhance GHG emissions efficiency measured as net crop farm income generated per unit of carbon emissions created. The 5 percent reduction in GHG emissions does cause marginal reductions in acres farmed and has marginal income ramifications. Beyond the 5 percent reduction target, gains in GHG emissions efficiency decline but remain positive in most counties through the 10 percent GHG reduction target. However, with a 10 percent GHG reduction, acreage and income reductions more than double compared to the 5 percent level. When GHG emissions are reduced by 20 percent from the baseline, the result is a major cropping pattern shift coupled with significant reductions in traditional row crop acreage, income, and GHG emissions efficiency.

Key Words: greenhouse gas emissions, carbon equivalents, sustainability, cap and trade

With the Waxman-Markey Bill passing the House and the administration's push to reduce greenhouse gas (GHG) emissions by late 2009, the likelihood of the implementation of some form of a carbon emissions policy is increasing. While GHG emissions have been modeled for quite some time, many policy analyses to date have focused either on global/national effects on agriculture (Reilly and Paltsev 2009, Outlaw et al. 2009, Beckman, Hertel, and Tyner 2009, McCarl 2007), individual field test plots, or soil- and climate-based models that work at the field level (Century Model 1995, Parton et al. 1987). The former lack detail at the local level while being representative and relevant at the macro level, while the latter prove very detail-oriented, but findings can often not be generalized to larger regions and hence typically lack inclusion of likely responses to changing economic conditions. Therefore, a methodology to both measure GHG emissions and analyze carbon emission policy impacts that strikes a middle ground is needed—a methodology sufficiently detailed to embody local production, soil, and climate differences, and yet sufficiently representative to provide pertinent economic information for agricultural producers and policymakers at the local, county, state, and federal levels.

The purpose of this study is to estimate and analyze GHG emissions of the six largest row crops (corn, cotton, rice, sorghum, soybeans, and wheat) produced in Arkansas across the range of the most predominant production practices documented by the University of Arkansas Coopera-

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tive Extension Service (UACES). The estimation of GHG emissions by production method uses a cradle-to-farm gate Life Cycle Analysis (LCA) on a county-by-county basis and offers the opportunity of estimating the trade-offs between GHG emissions and agricultural returns between crops and within crops using different production methods.

More specifically, GHG emissions were estimated by crop and production practice, varying within and across counties in conjunction with cost of production data, allowing for the estimation of impacts of various carbon-reduction policies on (i) county and agricultural income redistribution throughout the state as a result of crop acreage reallocation, (ii) crop acreage reallocation, which in turn is affected by the capping of GHG emissions, and (iii) the capping of GHG emissions itself. The objectives of this study are to (i) quantify the amount of GHG emissions as they vary by crop, production practice, and county, (ii) calculate crop acreage reallocation and farm income redistribution at the county level when GHG emissions are reduced with a cap-and-trade system from a 2007 baseline by 5, 10, and 20 percent, and (iii) compare changes in carbon emission efficiency measured as net crop farm income generated per ton of carbon emissions created.

Background

Life Cycle Analysis

The Life Cycle Analysis (LCA) put forth in this study included both direct and indirect GHG emissions. Direct emissions are those that come from farm operations. Examples are carbon dioxide (CO_2) emissions from the use of diesel by tractors and irrigation equipment and the use of gasoline by farm trucks. Indirect emissions, on the other hand, are emissions generated off-farm as a result of the manufacturing of inputs used on the farm. Examples are GHG emissions from the use of natural gas in commercial fertilizer production.

Included in the LCA are GHG emissions of agricultural inputs involved in the production of commodities up to the farm gate (e.g., fertilizer, herbicides, pesticides, fuel, agricultural plastics, and other chemicals). Excluded are emissions generated during drying, transport, or processing of a commodity that occurs after the farm gate. Also excluded from this study are embedded carbon emissions as a result of upstream production of equipment and tools used on-farm for agricultural production. Finally, as is common with many LCAs, the analysis excludes those inputs that contribute less than 2 percent of total emissions.

Methane Emissions from Rice

Given that Arkansas is the largest producer of rice in the United States, methane (CH_4) emissions—a direct result of flooded rice cultivation and the anaerobic decomposition of organic matter in the soil—were included. Tyler (2009) analyzed 12 rice production seasons from two southern rice-producing states (Texas and Louisiana) and found that the average methane released from rice production was 268.1 mg/m^2 of methane per day, or an equivalent of 1,367 lbs of carbon per acre of paddy rice per year.[1] Relative to the rest of the row crop agriculture, rice production thus releases a large amount of methane, a greenhouse gas 25 times more potent than carbon dioxide.

Soil and Nitrogen Effects

It was assumed that soil carbon remained constant, or at equilibrium, and so there was no net carbon sequestration or soil CO_2 emission (Kahn et al. 2007) as a result of crop production. Soil nitrous oxide (N_2O) emissions stemming from the application of nitrogen fertilizer have been identified as a major contributor to GHG emissions from crop production (Bouwman 1996, Smith 1997, Yanai 2003, Del Grosso et al. 2005, Snyder et al. 2009). The International Panel on Climate Change (IPCC) (IPCC 2007) Third Assessment Report conversion factor of 298 units of CO_2 emitted per unit of N_2O applied is commonly used and based on a one percent emissions loss from nitrogen application. This amounts to 1.27 lb of carbon equivalent (CE) emissions per pound of elemental nitrogen applied.[2] However, given the large variation in N_2O release, which is a function

[1] 268.1 mg/m^2 of methane per day times 4,046 m^2/acre times 25 CO_2/CH_4 times 12/44 C/CO_2 divided by 453,592 mg/lb equals a carbon equivalent of 16.3 lbs/ac per day. The average number of days under the flood in Tyler's (2009) study was 83.84, resulting in 1,367 (83.84 × 16.3) lbs of carbon equivalent per acre per year from methane release in rice production.

[2] For each pound of N applied we get 44/28 N_2O/N_2 times 0.993 percent emitted times 298 CO_2 / N_2O times 12/44 C/CO_2 equals 1.27 C/N applied.

of timing and method type of nitrogen as well as climatic and soil conditions, we chose to perform the analyses with and without this N_2O emissions load.

Carbon Emissions Calculations

Given the above complexities in dealing with the estimation of GHG emissions, previously reported carbon equivalent (CE) emission factors were used to estimate the amount of emissions generated as a result of input use by production practice (Table 1). In essence, multiple GHGs associated with global warming were converted to their carbon equivalents to obtain a "carbon footprint"—a process stemming from a rich engineering literature on carbon equivalence. Values provided by the U.S. Environmental Protection Agency (EPA) (EPA 2007, 2009) were used for diesel and gasoline combustion emissions and combined with EcoInvent's life cycle inventory database through SimaPro (2009) to calculate the upstream emissions from the production of fuel. Values provided by Lal (2004), a synthesis of numerous studies measuring carbon emissions from farm operations, were used for all other inputs.

Since many different types of fertilizers (e.g., ammonium nitrate, liquid nitrogen, diammonium phosphate, urea, potash, phosphates, and combinations of the above) require different amounts of energy, production technologies, and hence CO_2 emissions during fertilizer production, Lal's (2004) CE emission values for nitrogen, phosphorus, and potassium were used to arrive at GHG emissions from combinations of fertilizers used in production by weighting by their component values (i.e., 1 lb of 18-24-15 N-P-K fertilizer would have 0.18 × 1.3 CE from N + 0.24 × 0.2 CE from P and 0.15 × 0.16 CE from K, or 0.31 CE per pound of 18-24-15 fertilizer applied without N_2O emissions and 0.54 CE with N_2O emissions).

Crop Production Information

Annual estimates of cost of production for each of the six largest crops are available from the University of Arkansas Cooperative Extension Service (UACES) (UACES 2008) and are reported for different soils, production regions, and production practices commonly used by producers (see the appendix for a description of major changes in production methods). Using the carbon equivalents from Table 1 and the recommended input usage from each of the 57 extension production budgets, a per acre GHG emission level could be calculated for each production budget (Table 2). As shown, per acre GHG emissions are highest for rice production, with GHG emission rates roughly four times higher than for corn, the next highest emitter. The principal component of this large carbon footprint is the methane released during paddy rice production.

Table 2 and Figure 1 also illustrate the difference in GHG emissions per acre between irrigated and non-irrigated production methods (highlighted in Figure 1 with the letter D for dryland or non-irrigated production). Pumping water for irrigation requires a significant amount of energy (typically diesel) and contributes significantly to the total GHG emissions when comparing irrigated to non-irrigated production. Including or excluding N_2O emissions affects corn and soybeans the most/least, respectively, given the relatively high level and lack of nitrogen fertilizer application for the respective crops. The application of agricultural chemicals (pesticide, fungicide, and herbicide) affects the GHG emissions for cotton the most. Figure 1 demonstrates the significant impact of using different production practices across different regions in the state. On average, soybeans had the lowest GHG emissions per acre, followed by wheat, sorghum, cotton, corn, and rice, respectively.

While these relative rankings are important, they fail to take into account the profitability of each crop. That is, if a carbon policy was implemented, that does not imply that there would be a large increase of dryland soybean acres (the smallest emitter) and a large decrease of rice acres (the largest emitter). In fact, in terms of profitability, rice is highest among the portfolio of crop land use choices available in the Arkansas Delta, and as such producers would be most reluctant to curtail its production. Another key point that a single "carbon emissions score" fails to take into account is the efficiency of input use. As inputs remain constant and yield increases, carbon per lb/bushel of commodity decreases. While some crop production methods (center pivot irrigation, for example) have high levels of inputs (fuel), they also have a relatively high yield, and so the GHG emissions per lb/bushel of commodity is much closer to the mean of low-input and low-yielding

Table 1. Carbon Equivalent Emission Factors

Input	Pounds of Carbon-Equivalent per Unit of Input Used	Source
Fuel (gal)		
diesel	7.01	SimaPro (2009), EPA (2007, 2009)
gasoline	6.48	SimaPro (2009), EPA (2007, 2009)
Fertilizer (lb)		
nitrogen	1.30	Lal (2004)
phosphorus	0.20	Lal (2004)
potassium	0.16	Lal (2004)
lime	0.06	Lal (2004)
N_2O emissions	1.27	Solomon et al. (2007)
Herbicide/Harvest Aid/adjuvant (pt or lb)	6.44	Lal (2004)
Insecticide/fungicide (pt or lb)	5.44	Lal (2004)
Methane (acre of paddy rice)	1,367	Tyler (2009)

production practices of non-irrigated crops, for example. On the same note, as new seed technologies are adopted that have lower input usage (e.g., hybrid rice) while maintaining yield, GHG emissions per lb/bushel of crop will decline as well. So, to imply that rice acreage will decrease because it has the largest carbon footprint is looking at only one side of the equation. Profitability in terms of input to output efficiency must be analyzed at a county level and by production method to estimate how crop land use choice will change under various carbon policies.

Modeling County Crop Production

Profitability and Historical Acreage Limits

An Arkansas state model that tracks crop profitability and resource use similar to that used by Popp, Nalley, and Vickery (2010) was necessary to model producer behavior on a county-by-county basis. Tracking fuel, labor, fertilizer, chemical, and irrigation water/plastic piping use as reported by UACES was used to not only calculate GHG emissions but also to conduct crop profitability analyses by comparing county yields and associated revenues to cost of production. Given the array of production methods discussed above (Table 2), crop-specific extension experts were consulted to determine which of the reported production methods were most prevalent in each of the nine crop-reporting districts (CRD) as defined by the Arkansas Agricultural Statistics Service. That is, rice extension experts were asked to determine which of the eight possible rice production methods in Arkansas were most frequently used within each CRD. This effort resulted in CRD-specific cost of production and resource use estimates. County-level average yields from 2004 to 2007 (USDA 2008a) helped determine returns above total specified expenses to land, management, and capital (*NR*), which in turn were used to model producer crop allocation decisions for all 75 counties in Arkansas.

The model is constrained by historical land use decisions to reflect technological, socioeconomic, and capital investment barriers. Hence, historical information about harvested crop land (including all crops, fruits, vegetables, hay land, and hay yield), pasture, CRP, and irrigated acres was collected from USDA Census of Agriculture data for 1987 through 2007. County-specific average Conservation Reserve Program (CRP) payments for 2007 were obtained from the USDA's Farm Service Agency (USDA 2008). Data for annual harvested acres for the traditional crops were available electronically by county from the Arkansas Agricultural Statistics Service from 1975 to 2007 (USDA 2008a).

With the possibility of emission restrictions requiring crop land to be idled, an alternative land

Table 2. Greenhouse Gas (Carbon Equivalent) Excluding N_2O Emissions in Pounds per Acre for Each of the 61 Major Production Methods for the 6 Largest Row Crops, Hay, Pasture, and CRP in Arkansas

Crop (*Region*)	Production Practice	Carbon Equivalent Emission (lbs/ac)	Crop	Production Practice	Carbon Equivalent Emission (lbs/ac)
Corn	RR furrow clay soil (1) [a]	571.07	Sorghum	Center pivot loamy soil (37)	367.44
	RR furrow loamy soil (3)	492.98		Furrow loamy soil (38)	332.46
	BT/RR furrow loamy soil (4)	492.98		Flood loamy soil (39)	326.71
	BT furrow loamy soil (5)	477.59		Non-irrigated mixed soil (40)	247.43
	Conventional center pivot loamy soil (2)	554.63			
	Conventional furrow loamy soil (6)	477.59	Full-	RR flood (11)	232.07
			season	RR furrow (12)	228.31
Cotton	BG/RR center pivot stale seed bed 12 row (47)	469.50	soybean	RR center pivot (13)	221.19
	BGII/RRFlex center pivot no-till 12 row (49)	458.14		RR boarder irrigated (17)	193.26
(Northeast)	RRFlex furrow stale seed bed 12 row (52)	455.48		RR non-irrigated (19)	109.04
	LL furrow stale seed bed 12 row (54)	440.32		Conventional flood (14)	212.82
	RR non-irrigated stale seed bed 8 row (56)	362.94		Conventional furrow (15)	209.07
	BG/RR furrow conventional till 12 row (44)	479.42		Conventional center pivot (16)	201.94
	BG/RR center pivot stale seed bed 12 row (46)	469.50		Conventional boarder Irrigated (18)	174.01
(Central)	WS/RRFlex furrow stale seed bed 12 row (48)	458.17		Conventional non-irrigated (20)	89.79
	BGII/RRFlex furrow stale seed bed 12 row (51)	455.48			
	BG/RR furrow stale seed bed 12 row (53)	455.48	Double-	RR furrow (21)	205.60
	RR non-irrigated stale seed bed 8 row (57)	348.42	cropped	RR center Pivot (22)	205.48
	BG/RR center pivot stale conventional till 8 row (41)	513.67	soybean	RR flood (23)	202.23
	BG/RR furrow stale seed bed 8 row (42)	480.62		RR center pivot no-till (27)	173.15
(Southeast)	BG/RR furrow conventional till 12 row (43)	479.48		RR boarder irrigated (28)	170.55
	BGII/RRFlex center pivot stale seedbed 12 row (45)	470.63		RR furrow no-till (29)	158.89
	BGII/RRFlex furrow stale seedbed 12 row (50)	455.48		Conventional center pivot (25)	188.33
	RR non-irrigated stale seed bed 8 row (55)	363.30		Conventional furrow (24)	188.45
				Conventional flood (26)	185.08
Rice [b]	Conventional seed clay soil (31)	2,010.47		Conventional boarder irrigated (30)	153.40
	Conventional seed silt loam soil (32)	1,947.76			
	Conventional no-till silt loam soil (34)	1,937.85	Wheat	After rice clay (7)	284.23
	Clearfield silt loam soil (33)	1,942.51		After rice sand/silt loam soil (9)	266.27
	Hybrid silt loam soil (35)	1,905.91		After other clay soil (8)	272.25
	Conventional zero graded no-till waterseeded (36)	1,859.98		After other sand/silt loam soil (10)	242.31
Hay	Conventional (fertilized to NASS reported yields) (58)	186.68	CRP	Establishment charge for grass (61)	27.97
	Low input (low fertilizer 1 cut with weed control) (59)	149.03			
			Pasture	Estimated for 2 acres per cow without livestock emissions (60)	97.18

[a] Budget number for cross reference with Figure 1. // [b] Rice GHG emissions include the estimated 1,367 lbs of carbon attributed to methane gas release per acre.

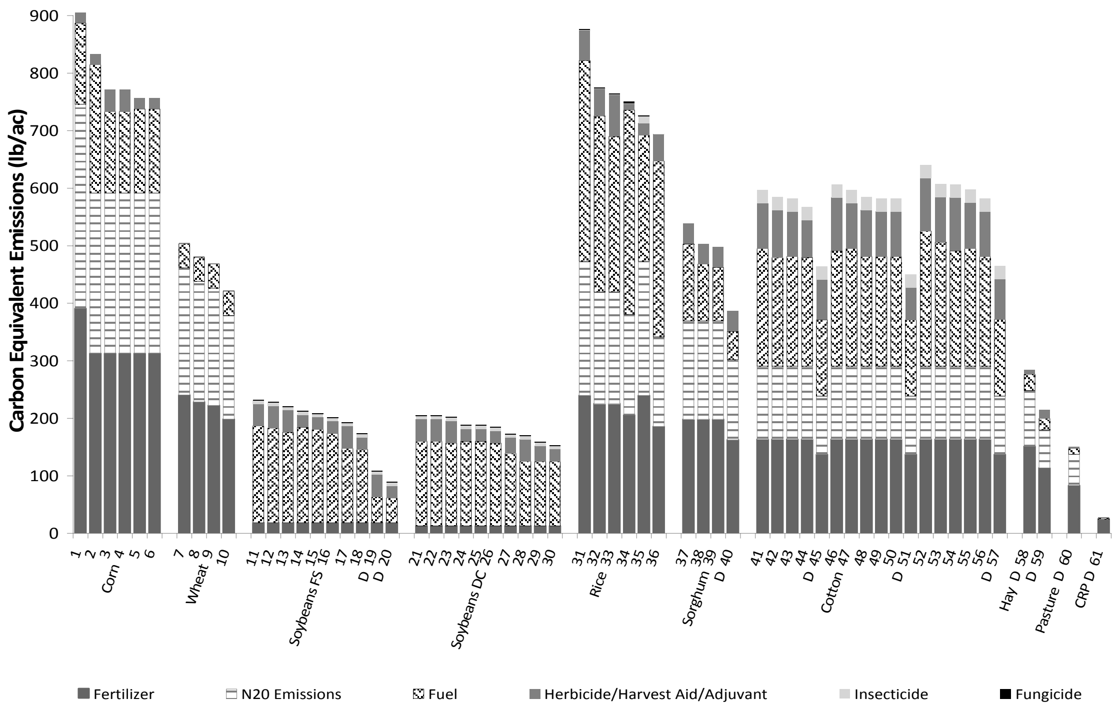

Figure 1. Decomposition of Total Greenhouse Gas Emissions by Crop and Production Types

Note: The carbon equivalent for rice does not include the 1,367 lbs attributed to methane release. "D" symbolizes non-irrigated enterprises. The crop number immediately below the x-axis refers to the production budget number in Table 2.

use choice was created to ensure that this land would not go to weeds or cause excessive soil erosion. The enterprise alternative chosen involves establishment of grass that would be harvested once per year in June or July to avoid potential weather-related problems with earlier harvest. The land is minimally fertilized and controlled for weeds to maintain the stand. As such, low-quality hay harvested at an average yield of 1.91 dry ton per acre results in sufficient revenue to offset most production costs. This alternative was chosen in lieu of pine tree production, as output price uncertainty would be lower, initial cash outlays smaller, reversibility to crop land easier, and annual revenue streams from commodity sales possible. This comes at the cost of lower carbon sequestration potential, the value of which is currently deemed an insignificant source of revenue at \$0.20 per ton of carbon sequestered and higher emissions in comparison with pine (Smith, Popp, and Nalley 2010).

Similar to Popp, Nalley, and Vickery (2010), the net return of Arkansas crop, hay, and pasture land are maximized by choosing crop acres (x) on the basis of expected commodity prices (p), county-relevant yield (y), and cost of production information (c) as follows:

$$\text{(1) Maximize } NR = \sum_{i=1}^{75}\sum_{j=1}^{14}(p_j \times y_{ij} - c_{ijn}) \times x_{ij},$$

subject to

$$xmin_{ij} \leq x_{ij} \leq xmax_{ij}$$

$$iacresmin_i \leq \sum x_{ij} \leq iacresmax_i$$
for irrigated crops only

$$acresmin_i \leq \sum x_{ij} \leq acresmax_i$$
for all crops except pasture and CRP,

where i denotes each of the 75 counties of production and j denotes 14 land management choices (irrigated and non-irrigated crop production, hay, pasture, and CRP), and *n* denotes different production practices specific to production region and exogenous to the model. *Xmin* and *xmax* are historical county acreage minima and maxima over the harvest years 2000 through 2007 for each crop (USDA 2008a). *Iacresmin* and *iacresmax* are the 1987 to 2007 Census-based reported irrigated acres that reflect technological, socioeconomic, and capital barriers to irrigation, again at the county level. *Acresmin* and *acresmax* are total harvested acres at the county level, as collected by the Census, and were amended by adding 10 percent of county CRP enrollments to the maximum harvested acre totals to reflect the potential for added acres from land coming out of CRP and the typical ten-year enrollment horizon of CRP acreage. Note that winter wheat was considered part of harvested acres even though this crop can be considered in double-crop rotations with soybean, corn, or sorghum crops. Crop price information (p_j) was based on the July futures prices as of December of the previous year and no commodity price program support (Great Pacific Trading Company 2008).[3] Basis expectations were set to zero for all crops, and prices were adjusted for hauling, drying, and commodity board check-off charges as appropriate. Direct and counter-cyclical payments were included in the price per unit of all crops (Table 3).[4] Yields (y_{ij}) reflect the per acre county averages for most crops. Since the Arkansas field office of the National Agricultural Statistics Service (NASS) does not differentiate between irrigated and non-irrigated double-cropped soybean and sorghum acreage, minor modifications as described by Popp, Nalley, and Vickery (2008) were made to double-crop soybean maximum and minimum acreage restrictions and grain sorghum yield differences between irrigated and non-irrigated production. Per acre cost of production estimates (c_{ij}) were developed as reported above.

[3]Wheat prices were based on the May futures prices as of September of the previous year given the different planting and harvest times compared to spring planted crops.

[4] All commodity prices were high enough that the loan deficiency payments were not triggered. Model runs without government payments are available from the authors upon request.

Carbon Policy Analysis

The above model [equation (1)] was run to develop a crop production baseline for Arkansas using 2007 conditions and resulted in a county-specific and statewide estimate of the amount of GHG emitted from agricultural production (*Carbonmax*). The model could then be restricted using the following constraint:

$$(2) \quad \sum Carbon_{ij} \times x_{ij} \leq Carbonmax \times (1 - a),$$

where $Carbon_{ij}$ are the carbon emissions by county i for land use choice j, x_{ij} are acres in production as described above, and a represents the targeted fraction of state GHG emissions to be reduced. That is, the baseline model allows producers at a county level to allocate acreage to maximize profit around a set of historical production constraints without a carbon restriction. A statewide carbon footprint was calculated from this baseline, and then 5, 10, and 20 percent reductions were imposed as new model constraints.

It is important to note that the carbon reduction is not a county-level reduction but rather a statewide constraint. This implies that the most/least GHG efficient crops—generating the most income per lb of GHG emitted—would be least/most affected by mandated reductions in statewide GHG emissions. While the model does allow the actual tracking of overall GHG emissions by county, it does not track exactly how GHG emissions are reallocated,[5] and therefore does not track cash flows that a county would pay/receive by the purchasing/selling of carbon emission permits. In essence, changes in county-level crop farm income represent only the changes associated with crop acreage reallocation. Noteworthy nonetheless is the fact that since the transactions between buyer and seller are a zero sum gain, the total

[5] For example, assume that county A and B both produce rice using only production method X (thus, theoretically the cost of production and emissions should be equivalent). If the average yield per acre in county B is 200 bu/acre and county A averages 175 bu/ac, because of the profit-maximizing nature of the model county B would continue to produce, whereas county A would curtail production if these were the only two options. Since each county grows more than one crop using an array of production techniques, it becomes difficult to track emissions trading where producers that curtail emissions would sell pollution credits to those that continue to pollute. As such, the model also does not take into consideration the actual price of the permit nor transaction costs associated with permit trading; this is pertinent information that warrants further research.

Table 3. Baseline Crop Acreage and Percentage Change in State Crop Acreage Given a 5, 10, and 20 Percent Reduction in Statewide Greenhouse Gas Emissions

	Baseline						Percentage Change from Baseline Acres and Income with GHG Emissions Reduction Policy Scenarios					
					$/C[d]		5%		10%		20%	
Crop	Acres	$/Acre	Price[b]	Govt. Pymt[c]	Avg.	SD	w/o N_2O	N_2O	w/o N_2O	N_2O	w/o N_2O	N_2O
Corn (irrigated)	520.8	200	4.00	0.11	798	273	3.7	1.1	0.7	1.9	(17.2)	(14.9)
Non-irrigated cotton	341.3	119	0.58	0.07	665	360	(1.3)	nc	(9.8)	nc	(55.9)	(30.3)
Irrigated cotton	667.5	148	0.58	0.07	629	158	12.9	14.2	8.4	13.1	(18.4)	5.6
Non-irrigated full-season soybeans	736.4	17	7.10	0.22	350	512	(1.3)	16.4	13.5	16.1	14.1	36.5
Irrigated full-season soybeans	1,658.7	25	7.10	0.22	225	209	0.4	0.2	0.6	1.0	nc	1.2
Irrigated double-crop soybeans	144.8	(22)	7.10	0.22	(235)	275	nc	nc	nc	nc	nc	nc
Rice (irrigated)	1,453.5	296	0.11	0.01	299	37	(9.6)	(6.2)	(12.9)	(12.5)	(12.9)	(12.9)
Wheat (non-irrigated)	844.3	63	4.60	0.32	491	177	(10.8)	(50.0)	(40.8)	(50.7)	(73.8)	(76.1)
Non-irrigated grain sorghum	105.8	78	3.80	0.18	633	235	(6.5)	0.1	(11.0)	(0.4)	(48.8)	(46.3)
Irrigated grain sorghum	86.6	114	3.80	0.18	657	172	17.5	(0.4)	(2.1)	1.0	nc	(25.1)
Hayland	1,428.2	40	60.00	NA	426	194	(0.3)	0.9	(24.5)	(24.2)	(23.9)	(24.5)
Low-input hay[d]	0	(4)	40.00	NA	(49)	NA	6,690	20,201	20,201	20,201	24,464	18,390
CRP	442.8	41	54.98	NA	2,900	748	nc	nc	nc	nc	nc	nc
Pasture	3,856.5	25	25.00	NA	515	NA	nc	nc	nc	nc	(57.6)	(57.6)
Total acres in production	7,998.0						(1.7)	(3.2)	(9.3)	(8.8)	(19.0)	(13.6)
Total irrigated acres	4,532.0						0.3	0.3	(2.6)	(1.4)	(9.7)	(5.1)
Total carbon emissions (tons)[e]	2,488.2											
Total net returns ($)	986,701						(2.9)	(2.9)	(7.6)	(7.0)	(22.9)	(18.2)

[a] In thousands of units. $/acre is acreage-weighted average returns per crop. $/C is acreage-weighted baseline net returns per ton of carbon emissions without N_2O emissions.
[b] Corn, wheat, beans, and sorghum are priced in dollars per bushel, rice in dollars per hundredweight, and cotton in dollars per pound of lint. Pasture is rental rates per acre, CRP is average payment per acre for the state but is county-specific, and hay is based on dollars per ton.
[c] Government payments are the summation of direct and counter-cyclical payments per unit (lb, bushel, cwt, etc.) per crop.
[d] Standard deviation of $/C is based on variation in yield and region-specific cost of production. Cost of production does not vary by yield, only by production method. Pasture and low-input hay are modeled at constant profit/yield across county given lack of data on production method detail.
[d] The baseline model does not allocate acreage to low-input hay. Thus, the numbers in this row represent total acres, not percentage change from the baseline.
[e] N_2O emissions add 363,070 tons or 12.8 percent above baseline total carbon emissions.

change in *state* crop farm income is only a function of crop acreage reallocation and not affected by permit trading cash flows with the exception of transaction costs. These assumptions are nonlimiting in the sense that carbon trading at current price levels, $0.20 per ton, is expected to be minimal. As shown in Table 2 and Figure 1, the largest GHG differential per acre among traditional row crop land use choices is between rice and non-irrigated soybeans at 1,920.68 lbs CE/acre. This differential in carbon emissions translates to $0.19 per acre using a carbon price of $0.20/ton versus per acre net returns of $295.74 on average for rice and $17.48 on average for non-irrigated soybeans. That is, the price of carbon would have to change substantially before a producer voluntarily switches from one acre of irrigated rice to one acre of non-irrigated soybeans.

So, by changing the amount of GHG emissions allowed for state crop agriculture, the model can be used to determine changes in crop acreage allocation and the overall profitability implications of a reduction of GHG emissions specifically targeted at Arkansas crop agriculture.[6] The analysis does assume that producers will choose only from current production practices and does not include the possibility of the adoption of carbon-reducing production methods/technology, as current carbon prices provide little incentive to change. Excluded from the model are also monitoring costs for enforcing carbon emission restrictions. Another important simplifying assumption is no changes in input prices that are anticipated with any sort of carbon-emission reduction policy. Since input prices are exogenous in this model, it assumes that producers will face the same input prices regardless of the emission reduction amount. Further research is warranted on the effects of emission policies on input prices.

By modeling different reductions in GHG emissions, estimates of crop acreage and net farm agricultural income changes for each of the 75 counties in Arkansas, providing valuable insights about which crops/industries would stand to lose the most acreage or production if emission restrictions were imposed on agriculture using current production technologies. This does assume that crop prices do not respond to changes in Arkansas crop acreage, an assumption that is put into the context of price determination by global changes in production, with Arkansas' production playing a minor role.

Results

The crop-specific baseline acreage and carbon footprint from the unconstrained model are illustrated in Table 3.[7] The baseline acreage was validated and found to be within 15 percent of actual 2007 planting for corn, grain sorghum, hay land, pasture, and soybeans, and within 20 percent of the actual 2007 wheat and cotton acreage. Full season soybeans and rice are estimated as the two largest crops in Arkansas, with 1.66 and 1.45 million acres, respectively. Table 3 also presents the impacts of a 5, 10, and 20 percent reduction in GHG emissions on cropping patterns, acres in production, irrigated acreage, and net agricultural returns. Figures 2 and 3 highlight differences in GHG emissions and agricultural income for various policy scenarios with and without the inclusion of N_2O emissions.

As expected with a cap-and-trade type emissions restriction policy, not all counties are affected equally, and hence some counties offer higher emission reductions than others regardless of the amount of emission restrictions imposed (Figure 2). Further, the changes in emissions reduction by county differ whether N_2O emissions are included or not. A similar observation occurs in Figure 3 when analyzing changes in income. While initial emission reductions appear to occur more in the eastern part of the state (the Arkansas Delta), where traditional row crop production occurs, emission reductions required to meet a statewide 20 percent goal appear to be mainly sourced from the western part of the state. As demonstrated in Table 4, this is likely a function of the amount of land use substitution possibili-

[6] This assumes that only crop agriculture in Arkansas would be involved and treats Arkansas like a closed economy. That is, agriculture does not trade permits with coal-powered electricity-generating facilities, for example. As stated previously, this also assumes that carbon sequestration is either equal to zero or not rewarded in the form of offsets.

[7] Interestingly, the state baseline carbon emissions with government payments (CCP and direct payments) included in the "market" price are roughly 19.3 percent (2,488.2 tons, Table 3) less than the baseline (2,968.7 tons) without the government payments. This is attributed to the fact that with government payments, dryland cotton acreage (a low emitter) increases substantially, and corn (a relatively high emitter) acreage decreases. Results without government payments are available from the authors upon request.

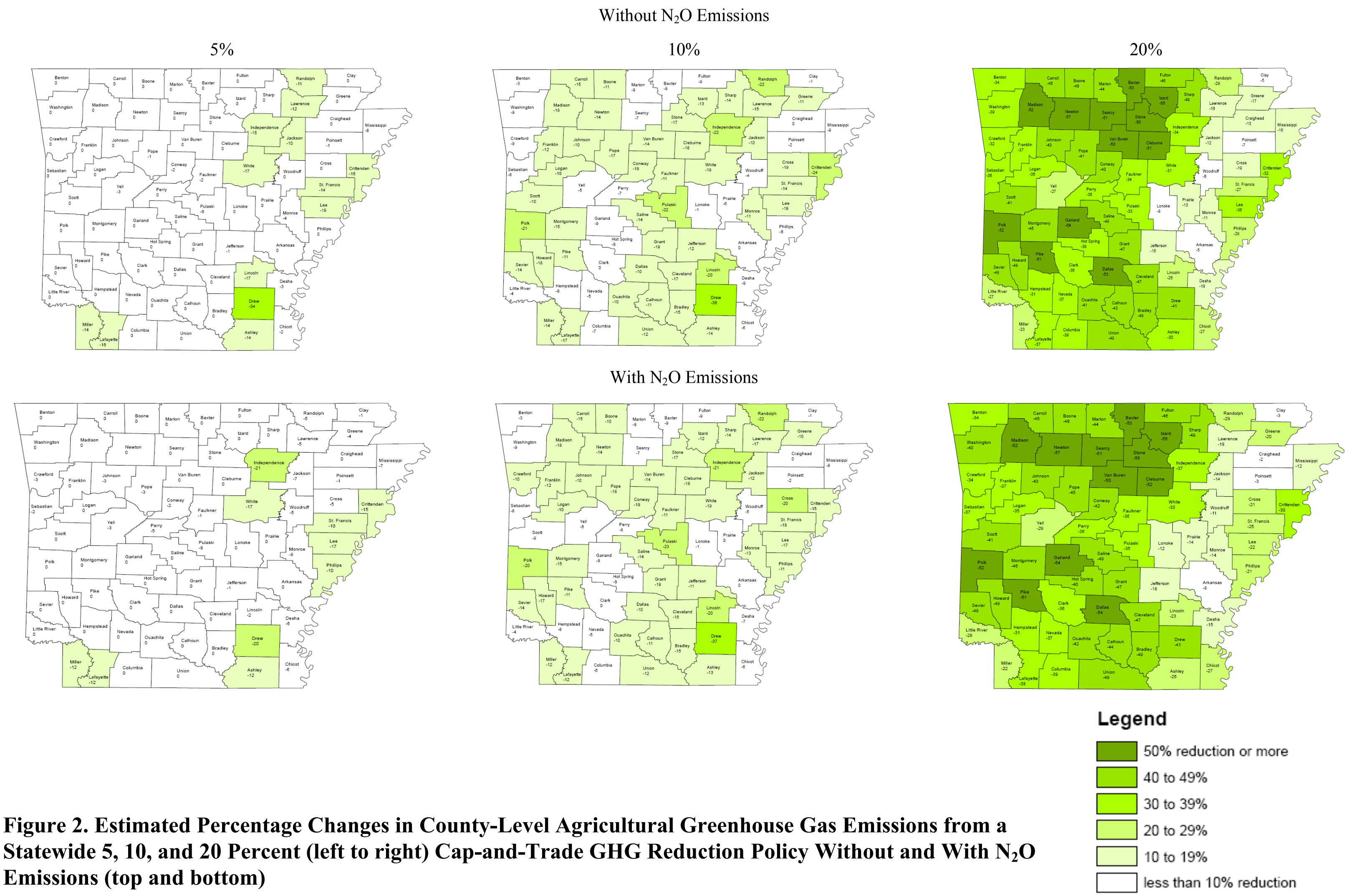

Figure 2. Estimated Percentage Changes in County-Level Agricultural Greenhouse Gas Emissions from a Statewide 5, 10, and 20 Percent (left to right) Cap-and-Trade GHG Reduction Policy Without and With N_2O Emissions (top and bottom)

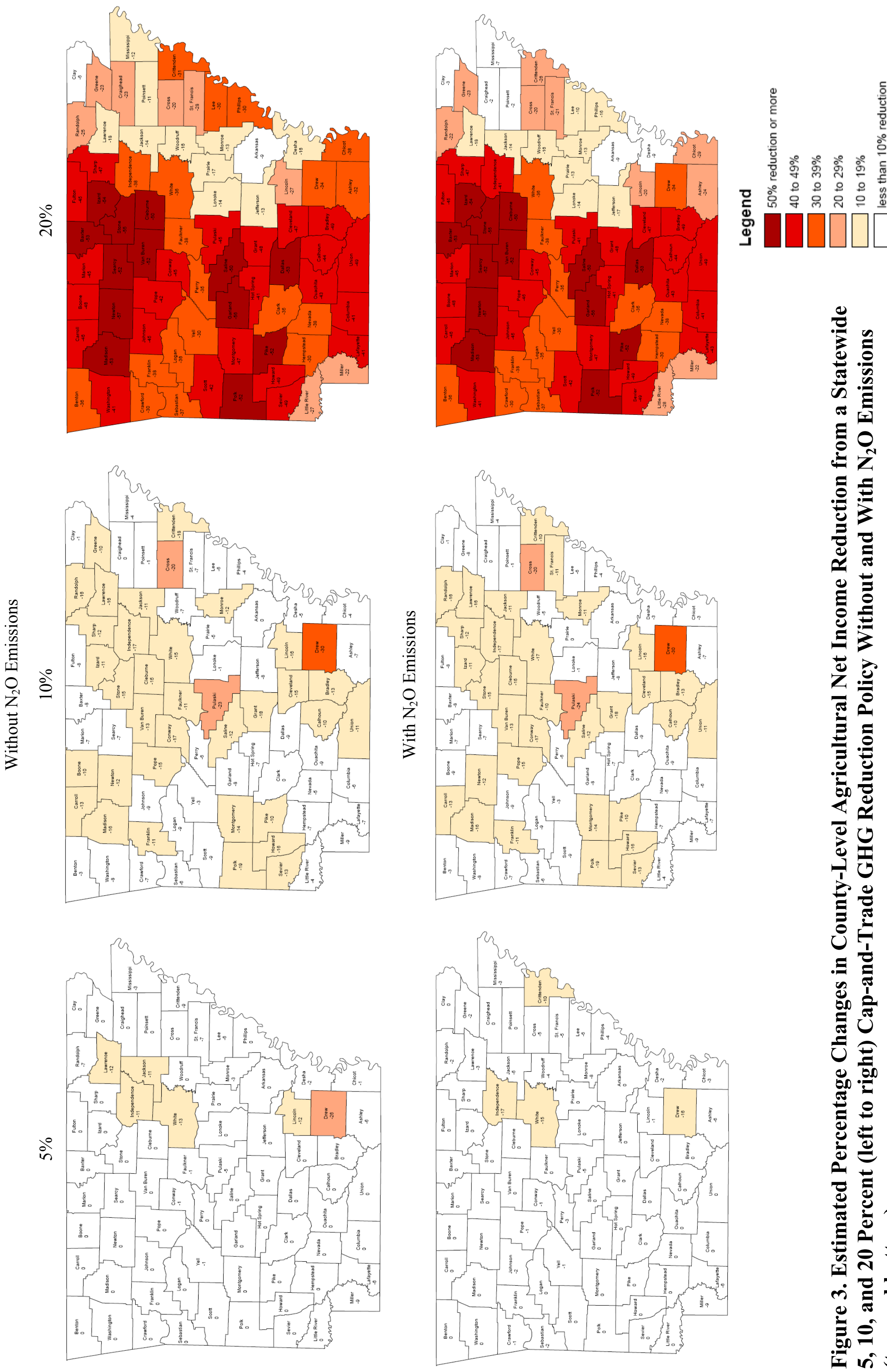

Figure 3. Estimated Percentage Changes in County-Level Agricultural Net Income Reduction from a Statewide 5, 10, and 20 Percent (left to right) Cap-and-Trade GHG Reduction Policy Without and With N_2O Emissions (top and bottom)

Table 4. Changes in Crop Rotation and Carbon-Equivalent Emissions for Counties Selected on the Basis of Degree of Land Use Substitution Possibilities and Overall County Profitability (low, high, and medium from top to bottom) (N_2O emissions excluded)

County	Measure	Corn	Cotton Irr.	Cotton Non-Irr.	Sorghum Irr.	Sorghum Non-Irr.	Soybean Irr.	Soybean Non-Irr.	Rice	Wheat	Hay Conv.	Hay Low	Total Acres[a]
Washington	NR $/ac	--[b]	--	--	--	--	--	--	--	--	$40.30	$(3.66)	--
	$/lb C	--	--	--	--	--	--	--	--	--	$0.22	$(0.02)	--
	lb C/ac	--	--	--	--	--	--	--	--	--	186.86	149.03	--
	Min ac	--	--	--	--	--	--	--	--	--	64,082	--	68,934
	Max ac	--	--	--	--	--	--	--	--	--	84,648	85,974	85,974
	Base ac	--	--	--	--	--	--	--	--	--	84,648	--	84,648
	5%[c]	--	--	--	--	--	--	--	--	--	nc	nc	nc
	10%	--	--	--	--	--	--	--	--	--	(15,714)	nc	(15,714)
	20%	--	--	--	--	--	--	--	--	--	(15,714)	nc	(15,714)
Poinsett	NR $/ac	$97.79	$154.20	$132.39	$148.21	$111.00	$35.76	$25.22	$303.14	$46.69	$40.30	$(3.66)	--
	$/lb C	$0.44	$0.33	$0.36	$0.42	$0.45	$0.16	$0.25	$0.15	$0.18	$0.22	$(0.02)	--
	lb C/ac	503.27	463.10	362.94	346.37	247.43	225.55	99.42	1,980.22	255.78	186.86	149.03	--
	Min ac	2,000	56,700	4,100	500	500	109,000	20,200	117,000	7,500	1,495	--	190,302
	Max ac	11,500	40,000	22,000	2,250	2,250	143,500	39,000	136,000	42,000	2,217	372,889	362,840
	Base ac	11,500	56,700	22,000	2,250	2,250	109,000	20,200	119,120	18,325	1,495	--	362,840
	5%	nc	nc	nc	nc	nc	nc	10,103	nc	(10,825)	722	nc	nc
	10%	nc	nc	nc	nc	nc	nc	12,945	(2,120)	(10,825)	nc	nc	nc
	20%	nc	nc	nc	nc	nc	nc	12,945	(2,120)	(10,825)	nc	nc	nc
White	NR $/ac	$124.85	--	--	$108.06	$70.47	$(16.59)	$(25.35)	$236.26	$20.50	$40.30	$(3.66)	--
	$/lb C	$0.25	--	--	$0.31	$0.28	$(0.07)	$(0.25)	$0.12	$0.08	$0.22	$(0.02)	--
	lb C/ac	503.27	--	--	346.37	247.43	225.55	99.42	1,980.22	255.78	186.86	149.03	--
	Min ac	1,600	--	--	200	200	23,000	13,500	14,000	1,700	34,031	--	137,793
	Max ac	3,500	--	--	1,500	1,500	30,000	23,500	22,000	21,500	55,615	171,891	169,771
	Base ac	3,481	--	--	1,500	1,500	23,000	13,500	21,147	21,500	55,615	--	141,243
	5%	19	--	--	nc	nc	nc	nc	(7,147)	nc	nc	3,678	(3,450)
	10%	19	--	--	nc	nc	nc	nc	(7,147)	(13,512)	nc	17,190	(3,450)
	20%	(1,881)	--	--	nc	nc	nc	8,188	(7,147)	(19,800)	nc	17,190	(3,450)

[a] Total acres exclude pasture, CRP, and double-cropped soybeans as pasture acres are not counted in historical minimum and maximum harvested acres in this model. Double-cropped soybeans and CRP are not included as they are always at minimum acreage and CRP is not modeled to have substitution possibilities in the model.
[b] "--" means that the crop has not been grown in the county from 2000 to 2007. Under total acres the same symbol implies that the measure is not meaningful.
[c] "nc" means no change from the base acreage observed. Numbers in parentheses indicate declines in acreage compared to the baseline, whereas positive numbers indicate inreased acreage.

ties and the need to stay within historical acreage limits.

Crop Substitution and Acreage Limits

Table 4 shows detailed county-level results related to Washington, Poinsett, and White counties. These counties were chosen to show the impact of limited land use substitution possibilities as well as historical harvested acre limitations. Washington County, while profitable with hay and pasture production, has no history of row crop production, and hence the economic choice to reduce state-level emission reductions begins to impact that county at the 10 percent emissions reduction level when hay production declines. At the 20 percent emissions reduction target, pasture acres (not counted in historical harvested acres but tracked separately) go to their county minimum to enable a 20 percent state reduction in emissions even though these acres are still profitable and pasture is the third lowest emitting crop (Figure 1 and Table 2). Hence, the response of Washington County with limited land use substitution possibilities is to curtail production only to allow more carbon-efficient counties to maintain their output level or marginally decrease their output to a lesser extent than Washington County.

The second county analyzed in Table 4 is Poinsett County, with the largest historical harvested acres and with the greatest number of possible choices for land use substitution. Note that in this county, production of non-irrigated soybeans—the lowest emitting crop (Figure 1 and Table 2)—and hay increases at the cost of wheat acreage to curtail emissions by 5 percent. Analyzing the 10 percent and 20 percent emissions scenario suggests a reduction of rice acreage to its historical minimum while adding additional non-irrigated soybean acres and dropping the initially added hay acres for non-irrigated soybeans with lower emissions. Notable, in this county is the relatively high level of profitability per acre across all enterprises. The most carbon efficient (highest NR/lb of carbon emitted) crops stay unchanged by emission restrictions, as other counties offer emission reductions at a lower overall cost to state returns and hence overall harvested acreage in the total acres column remains at historical maximum acres.

White County, which has an intermediate level of land use substitution possibilities, provides insights about how low-input hay would enter production. Also, with the exception of corn, this county exhibits less profitable yields for sorghum, soybeans, rice, and wheat than does Poinsett County, and hence acreage reductions to meet state-level emission restrictions are considered more likely. White County reallocates land use at the 5 percent emissions restriction level by first curtailing production of rice, the crop with the relatively low carbon efficiency but very high carbon emissions footprint. This allows the addition of modest corn acreage to offset profitability losses but also requires the addition of low-input hay to meet the minimum total acres harvested constraint of 137,793 acres. Higher emission reductions come at the cost of wheat acres, the least carbon efficient of remaining crop choices for acreage reductions (note that soybeans are already at their minima), offering a differential of approximately 106 lbs of carbon/acre compared to low-input hay at a profit loss of $24.16/acre. At the 20 percent reduction level, non-irrigated soybeans, even at their greater loss to the county, offer more carbon reduction than even low-input hay, and hence enter the crop mix.

Carbon Efficiency Changes

Trade-offs, such as those illustrated for a sample of counties in Table 4, are also summarized in Table 5. As illustrated above, crop land use choice to minimize emissions can lead to carbon efficiency improvements when counties that offer lower carbon efficiency trade off emissions with counties that provide more net returns per pound of carbon emitted. Thus, while the average $/C information by crop in Table 3 is important, significant variation in profitability exists across counties primarily as a function of yield. Hence, non-irrigated cotton acreage declines at lower emission restriction levels than does irrigated cotton acreage, for example, even though non-irrigated cotton acreage has a higher average carbon efficiency by shedding least efficient acres earlier than irrigated cotton acreage (note the higher standard deviation in $/C for non-irrigated cotton). Further, irrigated double-cropped soybeans are already at minimum historical acreage, and hence their low carbon efficiency yields no further acreage reduction with increasing emission restrictions. Also note that wheat shows much higher

Table 5. Changes in Carbon Emissions Efficiency Across All Counties in Arkansas

	Baseline		Emissions Efficiency Changes Under Policy Scenarios [a]				Baseline		Emissions Efficiency Changes Under Policy Scenarios [a]		
County	C [b]	$/C [b]	5%	10%	20%	County	C [b]	$/C [b]	5%	10%	20%
Benton	28.7	476.2	0.0	0.3	(36.7)	Arkansas	270.7	420.8	0.0	0.0	(13.7)
Boone	22.3	491.0	0.0	1.5	(35.7)	Crittenden	144.4	361.0	8.7	7.6	(9.7)
Carroll	22.1	486.4	0.0	2.0	(35.0)	Cross	252.0	298.4	0.0	(1.3)	(11.1)
Madison	22.0	479.1	0.0	2.1	(35.9)	Lee	146.1	430.0	16.0	16.0	(6.8)
Newton	8.0	488.9	0.0	1.9	(36.1)	Lonoke	203.7	352.9	0.0	(0.0)	(16.4)
Washington	31.5	475.0	0.0	0.9	(36.5)	Monroe	145.0	321.8	1.0	(1.7)	(16.3)
CRD 1	134.7	481.3	0.0	1.3	(36.1)	Phillips	164.6	528.1	0.0	2.3	(19.0)
						Prairie	172.5	419.9	0.0	0.8	(12.9)
Baxter	8.1	493.1	0.0	1.3	(36.1)	Saint Francis	143.6	362.0	7.7	7.7	(10.5)
Cleburne	10.5	498.9	0.0	2.9	(32.2)	Woodruff	161.9	234.4	0.1	(2.5)	(19.4)
Fulton	19.0	499.5	0.0	1.4	(35.0)	CRD 6	1,804.6	372.4	2.4	2.8	(13.5)
Izard	14.8	509.7	0.0	2.2	(32.4)						
Marion	10.8	494.6	0.0	1.1	(35.7)	Hempstead	18.6	506.5	0.0	1.2	(33.6)
Searcy	13.2	492.8	0.0	1.0	(36.3)	Howard	11.2	481.5	0.0	2.2	(35.3)
Sharp	13.2	511.5	0.0	2.6	(32.1)	Lafayette	22.7	326.8	12.4	12.4	(31.9)
Stone	11.2	494.4	0.0	2.7	(33.9)	Little River	16.6	518.8	0.0	0.8	(37.5)
Van Buren	9.9	475.0	0.0	1.5	(36.9)	Miller	36.6	319.5	6.1	6.1	(27.8)
CRD 2	110.6	497.8	0.0	1.8	(34.4)	Montgomery	6.7	475.7	0.0	1.6	(36.2)
						Pike	7.5	489.8	0.0	1.5	(35.5)
Clay	210.5	392.6	0.0	0.1	(14.6)	Sevier	11.6	479.3	0.0	1.7	(36.1)
Craighead	244.1	426.3	0.0	0.0	(14.3)	CRD 7	131.5	417.9	4.4	4.4	(33.5)
Greene	170.9	336.3	0.3	0.6	(16.7)						
Independence	54.2	303.0	5.3	5.9	(28.5)	Bradley	2.2	490.0	0.0	2.1	(33.9)
Jackson	230.3	244.8	(0.8)	(0.8)	(14.1)	Calhoun	1.5	491.3	0.0	1.5	(34.5)
Lawrence	223.9	272.6	0.0	(0.9)	(12.2)	Clark	6.1	526.4	0.0	0.0	(32.7)
Mississippi	224.1	553.3	5.1	5.7	(13.0)	Cleveland	2.8	478.0	0.0	1.9	(35.4)
Poinsett	311.6	361.4	0.1	0.4	(11.4)	Columbia	4.1	475.9	0.0	0.6	(36.8)
Randolph	95.5	385.6	4.0	7.2	(10.4)	Dallas	1.5	499.3	0.0	1.6	(33.7)
White	81.7	327.5	4.7	4.0	(24.4)	Nevada	6.8	487.5	0.0	0.6	(35.7)
CRD 3	1846.8	367.2	1.9	2.2	(13.0)	Ouachita	2.4	481.3	0.0	1.2	(35.6)
						Union	2.7	486.2	0.0	1.6	(35.3)
Crawford	15.3	512.3	0.0	2.0	(29.9)	CRD 8	30.0	493.3	0.0	1.0	(34.8)
Franklin	16.8	476.0	0.0	1.3	(35.7)						
Johnson	11.0	466.8	0.0	1.2	(37.3)	Ashley	76.8	381.2	8.9	8.8	(15.8)
Logan	20.7	494.7	0.0	1.4	(35.1)	Chicot	120.1	464.8	1.4	2.1	(21.2)
Polk	12.9	479.8	0.0	2.6	(35.2)	Desha	148.3	563.4	1.9	4.1	(13.8)
Pope	16.1	454.9	1.2	2.6	(35.8)	Drew	53.7	359.1	12.4	12.8	(8.2)
Scott	10.8	477.6	0.0	1.0	(36.4)	Jefferson	171.7	370.6	1.2	3.6	(13.7)
Sebastian	10.9	477.4	0.0	1.3	(35.9)	Lincoln	112.5	372.5	5.2	4.5	(10.7)
Yell	22.0	412.8	2.1	2.0	(33.1)	CRD 9	683.0	429.6	4.0	5.5	(13.6)
CRD 4	136.6	470.1	0.5	1.6	(34.7)						
						State Total	4,976.3	389.3	2.3	2.7	(16.6)
Conway	20.7	425.8	0.9	0.8	(36.8)						
Garland	27.2	429.6	0.8	0.6	(31.5)						
Grant	3.8	486.2	0.0	1.1	(37.1)						
Faulkner	3.3	469.4	0.0	1.9	(36.1)						
Hot Spring	6.1	483.0	0.0	0.9	(35.9)						
Perry	6.4	486.5	0.0	1.7	(34.2)						
Pulaski	26.4	293.2	0.6	(1.5)	(29.9)						
Saline	4.7	484.3	0.0	1.8	(35.1)						
CRD 5	98.6	405.5	0.9	1.5	(33.4)						

[a] Policy scenarios are state reductions in GHG emissions from a 2007 baseline in the amount of 5, 10, and 20 percent.
[b] C represents carbon emisssions in thousands of pounds, and $/C tracks agricultural income per county divided by tons of carbon emitted.

acreage reductions with N_2O emissions included at low levels of emission restrictions than if N_2O emissions are not included. This is a direct function of carbon efficiency. With N_2O emissions, curtailing wheat acres allows more carbon reduction benefits at relatively low profitability losses than if N_2O emissions are not included, and hence state income can be maintained by shedding fewer corn acres, increasing rather than decreasing irrigated cotton and requiring fewer low-input hay acres to meet historical harvested acreage constraints (Table 3).

Changes in Agricultural Income

While minor state-level reductions in profitability at low restriction levels are evident, larger ramifications become visible at the 10 percent level as even counties like Poinsett trade off profitable rice acres to meet emission restrictions. At both the 5 and 10 percent emission restriction levels, income drops by less than 5 and 10 percent because of the carbon efficiency increases noted in Table 5. At the 20 percent level, however, substitution possibilities that maintain total harvested acres are no longer possible and, as a last resort, crop production declines, with more or less equal declines in profitability, pending exclusion of N_2O emissions.

Possible Commodity Price Effects

Arkansas is the largest rice producer in the United States, so a large shift away from rice production should endogenously affect domestic and to some extent world price more so than with any of the other crops considered. Under the 20 percent reduction scenario, rice acreage declines by approximately 12.9 percent. To determine whether this acreage reduction scenario would yield a significant increase in rice price, an analysis using the Arkansas Global Rice Model (Wailes and Chavez 2010) was performed and indicated that there would be a domestic price increase of approximately 1.1 percent and a world price increase of 0.9 percent. Given that Arkansas has the largest impact in the rice market (compared to other row crops), this price change was considered to be sufficiently insignificant, and other commodity price changes through emission policy changes were not analyzed.

Conclusions

The objective of this study was to estimate the GHG emissions, in the form of their carbon equivalent, as a result of production of the major crops in Arkansas. Using a cradle-to-farm gate Life Cycle Analysis, both direct and indirect carbon emissions were estimated including production practice details commonly aggregated in other studies. Results of this analysis illustrate the differences in emissions on a spatial basis, as well as by production (tillage, irrigation, etc.) practice. This analysis provides a baseline for comparisons across counties and across production practices to see how inputs and spatially specific production practices impact GHG emissions in production of row crops. While the results are specific to Arkansas agriculture, the methodology implemented could be applied to any region.

Modeling crop production without GHG emission restrictions provided a baseline of 2007 production conditions and was subsequently used to compare the introduction of cap-and-trade type GHG emission reduction policies at varying levels of intensity. Statewide restriction on GHG emissions led to findings that suggest that moderate reductions in emissions can lead to carbon emission efficiency (dollars of output per ton of carbon emitted) improvements as a result of emissions trading. Targeted emission reductions beyond 10 percent, however, curtail carbon efficiency gains from trading emission permits, lower acreage in production, and significantly reduce agricultural income. Further, as a result of changes in crop mix and acreage reductions, significant spatial reallocation of producer income results in the absence of expected minor commodity price changes and no further CRP or like program acreage payments for idled land.

Ancillary effects of crop acreage changes for input and processing industries associated with agriculture in Arkansas were beyond the scope of this study but warrant further research. Also not included were transaction costs associated with enforcing emission restrictions as well as price-based incentives for pursuing less carbon intensive production.

The analysis did show, however, that crop acreage reallocation is sensitive to initial carbon emission assumptions. That is, changing modeling assumptions associated with N_2O emissions had an impact on crop acreage choices at the higher emission reduction targets as well as for wheat—the crop most affected by N_2O emissions relative to other land use choices. This suggests that, given the potential for large acreage reductions, it is quite plausible that lesser carbon emitting crops could enter the portfolio of producer land use choices, and in the event of high emission reduction targets that pasture land would be diverted to alternative enterprises with potential introductions of carbon offset markets and/or energy crop markets. Notable examples are CRP or like program acres as well as perennial, no-till forage and energy crops like switchgrass as well as tree crops. Of considerable debate, at that point, would also be changes in carbon sequestration as a natural result of crop, tree, or dedicated energy crop production if the assumption of steady-state carbon levels in soils, as made in this analysis, were to be relaxed.

In summary, modest reductions in emission targets will have minor negative farm income ramifications unless commodity prices rise to offset this effect via global declines in commodity production (all countries impose like emission restrictions on agriculture). Also, as expected, carbon emission efficiency increases due to gains from "trading" emission permits at modest emission reduction targets. However, at high emission reduction targets, both farm income and emission efficiency are lower than the baseline. Inclusion of secondary losses in input and processing industries as well as transaction costs associated with enforcing emission restrictions are expected to add to the negative aspect of mandatory emission reduction policies.

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Appendix. Differences Within and Across Crop Enterprises

KEY FOR ABBREVIATIONS USED IN APPENDIX

ac-in	acre inch	RR	Roundup Ready®
N	nitrogen	LL	Liberty Link®
P	phosphorus	WS	Roundup Ready Flex®
K	potassium	BG	Bollgard
B	boron	Bt	*Bacillus thuringiensis*
S	sulfur		

Corn

All corn production is irrigated using an average of 12 ac-in per production season. Fertilizer recommendations are 220 lbs of N, 75 lbs of P, and 75 lbs of K—with 60 lbs of extra N on clay. All rates are elemental. Other cost differences are a function of fuel efficiency and capital cost of irrigation method ranging from flood, furrow, to center pivot, as well as seed technology employed (conventional seed type, RR, Bt, and Bt/RR). Corn is grown mainly on loamy soils but also clay.

Cotton

Cotton production occurs under both irrigated and non-irrigated conditions. Fertilizer recommendations are 100 lbs of N, 60 lbs of P, 120 lbs of K, 10 lbs of B, and 1 lb of S—with 20 lbs less N for non-irrigated production. Cost differences are a function of equipment size (8 row vs. 12 row), seed technology (RR, LL, conventional seed type, WS, BG, Bt), boll weevil eradication zone, and irrigation amounts (center pivot 7 ac-in and furrow-irrigated at 12 ac-in).

Rice

All rice production is irrigated using 24–36 ac-in per production season, with zero-grade no-till fields requiring the fewest irrigation resources. All acres are flood-irrigated. Fertilizer recommendations range from 125 to 185 lbs of N, 0 or 60 lbs of P, and 0 or 90 lbs of K—with no P or K applied on no-till and clay soils, and extra N on clay. Other cost differences are a result of planting method (conventional seed type, no till, and stale seedbed) and related fuel and operating costs. Hybrid and LL varieties show significantly different seed and herbicide cost. Rice is grown mainly on silt loam soil but also clay.

Soybeans

Soybean production varies across irrigation method (no irrigation, center pivot, border, furrow, and flood) and seed technology (RR and conventional seed type). Fertilization recommendations include 35 lbs of P and 70 lbs of K for full season irrigated and dryland beans, and 30 lbs of P and 35 lbs of K for double-crop irrigated soybeans. A no-till option is available for double-crop irrigated soybeans.

Wheat

Wheat production varies across soil type (clay and sand/silt loam) and planting rotation (following rice or other crops). No irrigation is assumed for all wheat as all is grown over winter. Fertilizer application ranges from 140 to 175 lbs of N and 70 lbs of P depending on soil type and crop rotation.

Grain Sorghum

Grain sorghum production varies across irrigation type (center pivot, furrow, flood, or non-irrigated). Fertilizer application rates are 135 lbs of N, 60 lbs of P, and 70 lbs of K—with a decrease to 110 lbs of N, 50 lbs of P, and 60 lbs of K for non-irrigated production. Other cost differences are related to irrigation fuel efficiency and capital cost. Grain sorghum is grown on loamy soils exclusively.

Hay

Fertilizer recommendations are 2 tons of lime at planting and 77 lbs of N, 60 lbs of P, and 60 lbs of K. All hay land is non-irrigated. Stand life is eight years, with establishment charges prorated over the useful life of the stand. Fertilizer rates are a function of average nutrient requirements for mixed hay to achieve state hay yields. Round bales are staged at the side of the field.

Pasture

Fertilizer recommendation rates are 45 lbs of N, P, and K. All pasture is non-irrigated. Fertilizer recommendations are determined to ensure sufficient mixed forage growth to support 1 cow unit (includes calf, replacement heifer, and herd sire feeding requirements) using 2.7 acres for grazing at an estimated forage yield of 1.2 dry tons per acre. Establishment charges are similar to those for hay fields and prorated over an 8-year useful life. Lime application rates are 40 percent of those for hay.

Idle Land Converted to Low Fertilizer Single Cut Hay

Fertilizer recommendations are 2 tons of lime at planting, 52 lbs of N, 45 lbs of P, and 45 lbs of K, and based on a yield target of 1.9 dry tons per acre. A single cutting is performed in June or July, and supplemental chemical weed control is assumed. Cost of establishment is prorated over an 8-year stand life.