How A Cap-and-Trade Policy of Green House Gases Could Alter the Face of Agriculture in the South: A Spatial and Production Level Analysis.

Lanier Nalley
Assistant Professor
Department of Agricultural Economics and Agribusiness
University Of Arkansas
llnalley@uark.edu

Mike Popp
Professor
Department of Agricultural Economics and Agribusiness
University Of Arkansas

Corey Fortin
Graduate Research Associate
Department of Agricultural Economics and Agribusiness
University Of Arkansas

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Abstract

With the Waxman-Markey Bill passing the House and the Obama administration's push to reduce carbon emissions, the likelihood of the implementation of some form of a carbon policy is increasing. This study estimates the greenhouse gas (GHG) emissions of the six largest crops produced in Arkansas using 63 different production practices as documented by University of Arkansas Cooperative Extension Service. From these GHG estimates a baseline state "carbon footprint" was estimated and a hypothetical cap-and-trade carbon reduction of 5, 10, and 20% was levied on Arkansas agriculture. Results show that while a modest reduction in GHG emissions (5%) would only affect crop allocations amongst certain crops while marginally reducing state net returns, a 20% reduction would cause major cropping pattern shifts with some traditional row crops nearly disappearing.

Key words: Cap-and-Trade, carbon, sustainability

JEL classifications: Q28, Q52, Q54, Q56

Introduction

With the Waxman-Markey Bill passing the House and the new administration's push to reduce carbon emissions by late 2009, the likelihood of the implementation of some form of a carbon policy is increasing. While greenhouse gas(GHG) emissions have been modeled for quite some time, many policy analyses to date have focused either on global or national effects on agriculture (Reilly, 2009; Outlaw et al., 2009; Beckman et al., 2009; McCarl, 2007), individual field test plots, or soil and climate based models that work at the field level (Century Model and DAYCENT models); the former lack detail at the local level while being representative and relevant at the macro level while the later prove too myopic as they typically lack inclusion of likely responses to economic conditions. Hence a methodology is needed to analyze carbon policy impacts that strikes a middle ground – sufficiently detailed to embody local production, soil and climate differences and yet sufficiently representative to provide information for agricultural producers and policy makers.

The purpose of this study is to estimate and analyze GHG emissions of the six largest crops (corn, cotton, rice, sorghum, soybeans, and wheat) produced in Arkansas across the range of the 63 various production practices documented by University of Arkansas Cooperative Extension Service (UACES). This estimation of GHG emissions by production method focuses on effects from cradle-to-farm gate on a county by county basis using a Life Cycle Assessment (LCA). The LCA implemented in this study includes the 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 drying, transport, module building, ginning, or processing of a commodity. Further, the methodology applied in this analysis excludes tracking of inputs that contribute less than 5% of total emissions.

Estimates of GHG emissions by crop and production practice varying within and across counties in conjunction with cost of production data allows estimation of the impact of various carbon reduction policies on: (1) county and agricultural income redistribution throughout the state as a result of; (2) crop acreage reallocation which in turn is affected by; (3) the capping of GHG emissions. The objectives of this study are to: (1) quantify the amount of GHG emissions that are emitted by crop and production practice for the major crops in Arkansas; and (2) calculate crop acreage reallocation and farm income redistribution at the county level when a cap-and-trade system for carbon is implemented to reduce state GHG emissions by 5, 10, and 20%, respectively.

Life Cycle Inventory

The Life Cycle Inventory (LCI) developed for this analysis included direct and indirect 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. Excluded from this study are embedded carbon emissions as a result of upstream production of equipment and tools used on-farm for agricultural production. Further, 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). The analysis does include soil nitrous oxide (N_2O) emissions from application of nitrogen fertilizer, as nitrous oxide is 298 times more potent than carbon dioxide as a GHG (IPCC 2007). Also, since Arkansas is the largest producer of rice in the United States, methane

(NH_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 over 3 states (Texas, Louisiana, and California) and found that the average methane released from rice production was 0.00892 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 agricultural sector the rice and livestock industries release large amounts of methane, a GHG 25 times more potent than carbon dioxide.

Carbon emissions calculations

Given the above complexities in dealing with GHG emissions, previously reported carbon equivalent (CE) emission factors were used to estimate the amount of emissions generated as a result of input use (Table 1). In essence, multiple GHG's associated with global warming, are 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 US Environmental Protection Agency (EPA) were used for diesel and gasoline combustion emissions. EcoInvent's life cycle inventory database through SimaPro was used 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.

Nitrous oxide (N_20) from soil has been identified as a major contributor to greenhouse gas emissions from crop production (Bouwman, 1996; Smith, 1997; Yanai, 2003; Del Grosso, 2005; Snyder, 2007). The IPCC (2007) Third Assessment Report conversion factor of 298 units CO_2 per unit N_2O (or 81 units CE) was used based on a 1 percent loss from nitrogen application

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[1] This results in a carbon equivalent of 16.3 lbs/ac per day. The average 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.

rates. Although different types of nitrogen fertilizer (e.g. ammonium nitrate or urea) require different amounts of energy, and hence CO_2 emissions from N_20 production, we use a generic N_20 CE emission value because of the large amount of uncertainty of climatic conditions for a given field and more importantly the large variance even within a farm.

Crop Production Information

Annual estimates of cost of production for each of the six main crops are available from UACES and are reported for different soils, production regions and production practices commonly used by producers. Using the carbon equivalents from Table 1 and the recommended input usage from each of the 63 extension production budgets, a per acre GHG emission level could be calculated for each budget (Table 2). As shown, GHG emissions are highest for rice production with GHG emission rates roughly four times higher than corn, the next highest emitter. A principle component of this large carbon footprint is the methane released during production.

Table 2 and Figure 1 also illustrate the difference in GHG emission between irrigated and non-irrigated production. Fuel used by irrigation pumps, was the largest source of GHG emissions for each irrigated crop besides rice. Pumping water for irrigation takes a significant amount of energy (typically diesel) and contributes significantly to the total GHG emissions (Figure 1). Wheat, which is all non-irrigated in Akransas, provides an example of non-irrigated production as it portrays the relatively small share of fuel's GHG emissions in production.

Further, Figure 1 demonstrates the significant impact of nitrogen fertilizer and fuel as a percentage of the total carbon footprint of production. They play the largest role in GHG emissions when methane release from paddy rice production is excluded. Nitrogen fertilizer encompasses a large percentage of the total GHG due to the high amounts of energy (direct or indirect combustion of fossil fuels) required during its production. In addition, nitrogen applied to soil may be converted to nitrous oxide, a potent GHG.

On average, soybeans had the lowest GHG emissions followed by wheat, sorghum, cotton, corn, and rice, respectively. While these relative rankings are important, they do not 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 soybean acres and a large decrease of rice acres. In fact, in terms of profitability rice is the most profitable crop of the portfolio of crop land use choices in the Arkansas Delta and as such producers would be most reluctant to curtail its production. Another key point that this single “carbon score” fails to take into account is 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 CE per lb/bushel of commodity is much closer to the mean of other, low-input and low-yielding production practices such as non-irrigated crops. On the same note, as new seed technologies are adopted that have lower input usage while maintaining yield, carbon 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 only looking at one side of the equation. Profitability in terms of input and output effects 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

A state model that tracks crop profitability and resource use similar to that used by Popp et al. (2009) 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 for GHG emissions was also used 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 2004-2007 (USDA NASS, 2008) helped determine returns above the total specified expenses to land, management and capital (NR) that 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 harvested crop land information (including all crops, fruits, vegetables, hay land and hay yield), pasture and irrigated acres were collected from agricultural census data for 1987, 1992, 1997 and 2002 (USDA Census of Agriculture). Conservation Reserve Program (CRP) acreage, as well as average county specific CRP payments for 2007, were obtained from the USDA's Farm Service Agency (FSA, 2008). Annual harvested acres for the traditional crops were available electronically by county from the Arkansas Agricultural Statistics Service from 1975 to 2007 (NASS).

Similar to Popp et al. (2009) 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:

(1) Maximize $$NR = \sum_{i=1}^{75} \sum_{j=1}^{18} \left(p_j \cdot y_{ij} - c_{ij} \right) \cdot x_{ij}$$

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 18 land management choices (irrigated and non-irrigated crop production, hay, pasture and CRP). *Xmin* and *xmax* are historical county acreage minima and maxima over the harvest years 2000 through 2007 for each crop (USDA NASS, 2008). *Iacresmin* and *iacresmax* are the 1987 to 2002 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% 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 entertained 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).[2] Basis expectations were set to zero

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[2] Wheat prices were based on the May futures prices as of September of the previous year.

for all crops and prices were adjusted for hauling, drying and commodity board check off charges as appropriate. Yields (y_{ij}) reflect the per acre county averages for most crops. Since Arkansas NASS does not differentiate irrigated and nonirrigated double cropped soybeans and sorghum acreage minor modifications as described by Popp et al. (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.

Carbon Policy Analysis

The above model (Eq. 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:

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

where $Carbon_{ij}$ are 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% reductions were imposed as new constraints. It is important to note that the carbon reduction is not a county level reduction but rather a statewide constraint allowing counties to “trade” GHG emissions amongst themselves. As such, a county that is relatively efficient at producing output per unit of carbon emitted can “purchase” permits from counties that are not as efficient in production. That is, the model allocates crop production and associated carbon emissions not by which county uses the least GHG per acre, but rather by which county uses the least GHG per unit of output (GHG per acre/$ of profit per acre). While the model does not allow for the actual tracking of GHG emission permit trading, it does implicitly allocate GHG permits to those counties who use them most efficiently[3]. The model does not account for the revenue that a county would pay/receive by the purchasing/selling of carbon permits. Therefore the changes in county level crop farm income only represent the changes associated with crop acreage reallocation. Nonetheless, since the transactions between buyer and seller are a zero sum gain, the total change in state crop farm income is only a function of crop acreage reallocation and not affected by permit trading. These iterations were therefore run to determine changes in crop allocation and the overall profitability implications of a carbon cap-and-trade system[4]. Profitability and acreage distribution among crops were compared to the baseline to analyze how/if they diverge when carbon emissions were restricted by 5, 10 and 20%. This assumes that producers will only chose from current production practices and does not include the possibility of the adoption of carbon reducing production methods/technology. Excluded from the model are also monitoring costs for enforcing carbon emissions restrictions and trading costs. Essentially we assume that those transactions costs would not affect crop acreage allocation decisions.

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[3] For example, assume that county A and B both produce rice using only production method X (thus theoretically 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 be “issued” the permit. The model does not take into consideration the actual price of the permit nor transactions costs associated with it; this is pertinent information that warrants further research.

[4] This assumes that only agriculture would be involved in cap-and-trade and treats Arkansas like a closed economy. This also assumes that carbon sequestration is either equal to zero or is not rewarded in the form of offsets. While both of these assumptions are quasi-realistic, the focus of this study is not sequestration estimation nor was modeling all sectors of Arkansas’s economy feasible.

From these model iterations, estimates of crop acreage and net farm agricultural income changes for each of the 75 counties in Arkansas under each of the cap-and-trade scenarios could be estimated. These estimates provide valuable insights about which crops/industries would stand to lose the most acreage or production if carbon cap-and-trade was implemented for agriculture.

Results

The crop specific baseline acreage from the unconstrained model is illustrated in Table 3. The baseline acreage was within 10% of actual 2007 planting for corn, cotton, grain sorghum, hay land, pasture, and soybean, and within 15% of the actual 2007 wheat acreage. Full season soybeans and rice are estimated as the two largest crops in Arkansas with 1.6 and 1.4 million acres, respectively. Table 3 also presents the impacts of a 5, 10, and 20% reduction in GHG emissions on cropping patterns, irrigation water usage, acres in production, and net agricultural returns.

Five Percent Carbon Reduction

The 5% statewide reduction in GHG results in a relatively small acreage reallocation amongst most crops. Nonetheless, there is a large reduction in non-irrigated cotton (22%) and pasture (21%) acreage. Intuitively this makes sense given that non-irrigated cotton and pasture have a relatively high (for non-irrigated crops) average carbon footprint of 355.8l and 300 lbs/acre, respectively and a relatively low average profit per acre of $60.71 and $25.00, respectively. Interestingly, with an average carbon footprint nearly four times larger than that of other row crops, rice is estimated to decrease by only 1.19% in crop acreage. The high average profitability per acre of rice ($206.05) offsets its large carbon footprint. An example of the carbon footprint vs. profitability concept is Poinsett County. It is the largest rice producing county, and the county with the largest baseline GHG emissions, and yet experiences only a 0.11% reduction in county net returns as a result of 5% statewide reduction in carbon emissions. This implies that in a cap-and-trade situation, Delta rice producers would purchase emission permits, likely from pasture acres in Western Arkansas or from non-irrigated cotton producers in Eastern Arkansas. Also, while non-irrigated cotton loses acreage, irrigated grain sorghum experiences a 7.52% acreage increase under the 5% GHG reduction attributed to its relatively low (for irrigated crops) average carbon footprint of 342.20 lbs/acre and its moderately high average profit per acre $98.86 per acre.

Table 4 presents the county baseline of net farm income as well as the implications of the 5, 10, and 20% reductions in GHG. Crop reporting districts (CRD) 3, 6, and 9 represent the Arkansas Delta and make up approximately 80% of the crop income in Arkansas.[5] The Delta districts experience only a marginal decrease in average net farm income with a 5% GHG reduction at 1.08, 0.36, and 0.73% for CRD 3, 6, and 9 respectively. The CRDs with the smallest crop returns experience the largest percentage reductions in average net farm income with CRD 8, 5, and 2 losing 5.11, 9.65, and 11.65%, respectively (Table 4).[6] This indicates that those producers outside of the Arkansas Delta region would "sell" their carbon emissions permits to the producers in the Delta where carbon efficiency is relatively higher (Figure 2). While the Delta counties have a higher total carbon footprint per acre their carbon equivalent emissions per $ of farm income per acre is lower than the non Delta regions. The total decrease in state net return from the 5% reduction is estimated at 1.83%.[7]

Ten Percent Carbon Reduction

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[5] This does not include poultry or timber products.

[6] These losses do not reflect the revenue/costs from the carbon emission permits that would be sold/bought.

[7] These does not include the ancillary effects on the rice processing and cotton ginning industries

The results from the 10% reduction in GHG emissions are presented in Tables 3 and 4 as well. Rice acreage decreases by 11.49% from the baseline indicating that even its high profitability can't mitigate its large carbon footprint with a 10% reduction in GHG. Irrigated and non-irrigated sorghum experience the largest acreage increases from the baseline at 24.5 and 10.25%, respectively. The increased acreage to sorghum is a function of the relatively high profitability to carbon footprint ratio. Again, both non-irrigated cotton and pasture acreage experience a significant decrease in relation to the baseline. The Delta regions (CRD's 3, 6, and 9) experience an average crop income loss of 5.45%. The state as a whole loses 5.89% from its baseline net return, however; there are large spatial differences in net return reductions. For example, with the 10% GHG reduction 28% of the counties in CRD's 2, 5, and 8 lose at least 15% of their baseline net returns while 23% of the Delta counties lose less than 1% of baseline net agricultural returns. This again illustrates the transfer of carbon credits from the less efficient carbon using regions to regions of greater efficiency, namely the Delta (Figure 3).

Twenty Percent Carbon Reduction

The estimates from the 20% reduction in GHG iteration present some unique results. Initially the model could not find a crop acreage allocation within the historical state harvested acreage constraints using traditional crops, hay, pasture and CRP. Even with some crops (corn, dry cotton, wheat, and irrigated sorghum) at their historic minimums, the 20% reduction in GHG resulted in some land being diverted to an alternative energy crop, switchgrass, even with its price set to zero given the lack of a current market for this alternative. The rationale for the model's inclusion of switchgrass is its relatively low carbon foot print compared to other crop production that was required to meet the minimum state harvested acreage. The model converged with the introduction of 30,000 acres of switchgrass statewide. Even with the introduction of switchgrass there were an estimated 18.73% less acres in crop production with the 20% reduction in GHG. This illustrates an important point, a 20% reduction in GHG from the 2007 baseline looks to significantly alter cropping patterns in Arkansas that could not be met using traditional crops within historical crop acreage limits.

The first obvious result in the 20% GHG reduction scenario is the loss of 18.73% of the total acres in production from the baseline estimate. At the 20% GHG reduction level, the issue revolves less around that of profit and more on how to meet carbon emission targets within crop land use constraints. That is, current production methods even at or near historical acreage minima, are insufficient to meet a proposed 20% carbon emission reduction. The model's use of a money losing proposition (planting switchgrass without a switchgrass market and a zero price), exacerbates the economic impact but illustrates the point. Irrigated sorghum, corn, wheat, dry sorghum, and dry cotton all lose over 50% of their baseline acreage (Table 3). Rice is estimated to lose 13.5% from its baseline acreage. Non-irrigated soybeans and irrigated double cropped beans experience the largest increase from the baseline acreage at approximately 42 and 43%, respectively. However, this expansion is not attributed to their profit per acre but rather to the fact they have the lowest carbon equivalent emissions per acre. The total state reduction in net returns is 31.64% from the baseline estimate, or 207.71 million dollars. This does not include the losses likely to be experienced by the rice milling and cotton ginning industries that would result as function of reduced rice and cotton acreage. The Delta counties who were able to keep their net returns relatively stable at the 5 and 10% GHG emission reductions via the purchasing of carbon permits from other regions in the state now experience an average loss of 32.62% from the baseline because of the reduced number of permits to be purchased (Figure 4) . This highlights that not only would there be significant implications for crop redistribution across all counties, but also that, unlike the 5 and 10% GHG reductions, there are large statewide net return implications as well.

Conclusions

The objective of this study was to estimate the amount of carbon-equivalent greenhouse gas emitted in the 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 illustrated 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 in production of row crops. This analysis also provides a baseline to compare the introduction of various carbon reducing policies. Using 2007 as a baseline, a cap-and-trade system was implemented for a hypothetically closed agriculture model utilizing county level profit maximization to curtail GHG by 5, 10, and 20%.

From a carbon equivalent standpoint, fuel used for irrigation, was the largest source of GHG for each crop besides rice. Non-irrigated crops thus look to be advantageous to meet a statewide carbon reduction mandate. Nitrogen fertilizer was the second largest component of total GHG for each crop due to the high amounts of energy required in its production. In addition, nitrogen applied to soil may be converted to nitrous oxide, a potent greenhouse gas. Rice had the largest average carbon footprint, which was attributed to the large amount of methane released from paddy rice production.

For the 5 and 10% GHG reduction scenarios, the Arkansas Delta, where 80% of the state row crop income is generated, purchased permits from the less carbon emission efficient central and western parts of the state resulted in only a 0.93 and 5.45% reduction in net agricultural returns excluding the trading costs associated with carbon permits. The state as a whole experienced 1.83 and 5.89% crop income losses from the baseline for the 5 and 10% GHG reduction policies, respectively. Interestingly, rice whose average carbon footprint is approximately four times larger than other row crops only lost 1.19 and 10.25% of its baseline acreage under the 5 and 10% GHG reduction scenarios, respectively. This can be attributed to the fact that rice's high carbon footprint is mitigated by its high profitability. Essentially, if a cap-and-trade system was introduced, rice producing counties in the Arkansas Delta would purchase carbon permits from other parts of the state. Non-irrigated cotton is estimated to lose the most acreage under both the 5 and 10% reduction scenarios due to its relatively high carbon footprint to profit per acre ratio.

While the 5 and 10% reductions in GHG caused modest changes in state net return, the 20% reduction was estimated to reduce state net farm income by 31.64% from the baseline. The 20% reduction model could not converge given historic planting practices. An alternative crop with a low carbon footprint, switchgrass, had to be introduced to meet the historic minimum acreage harvested in Arkansas. Even with the introduction of switchgrass there was an 18.73% (1.46 million acres) reduction in crop land. While this acreage would likely be enrolled in CRP or another low carbon foot print land choice that results in income, unlike the current modeling choice of switchgrass, the important result of this research is that traditional row crops in Arkansas like corn, wheat, and cotton would lose more than 50% of their baseline acreage with current production practices. This decrease in acreage would also have ripple effects into the state commodity processing industry that were not included in this analysis.

These results show that while a modest reduction in GHG emissions would only affect crop allocations amongst certain crops while marginally reducing state net returns, a 20% reduction would cause major cropping pattern shifts with some traditional row crops nearly disappearing. While the model does not account for trading carbon amongst states or industries it does provide a relative sense of where each crop and production practice stands in terms of GHG emissions. This study illustrates that if agriculture is involved in a cap-and-trade type arrangement to reduce GHG, major crop pattern changes and significant reduction in crop production could result depending on the magnitude of the reduction.

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Table1. Carbon Equivalent Emission Factors

Input	Carbon-Equivalent	Source
Fuel		
Diesel	12.06 kg C/liter	USA EPA 2007 &2009, Sima Pro
Gasoline	11.16 kg C/liter	USA EPA 2007 &2009, Sima Pro
Fertilizer		
Nitrogen	1.30 kg C/kg	Lal, R. 2004
Nitrogen N_2O	1.27 kg C/kg	IPNI 2007, IPCC 2007
Phosphate	0.20 kg C/kg	Lal, R. 2004
Potash	0.16 kg C/kg	Lal, R. 2004
Lime	0.17 kg C/kg	Lal, R. 2004
Herbicide	6.44 kg C/kg	Lal, R. 2004
Insecticide	5.44 kg C/kg	Lal, R. 2004
Fungicide	5.44 kg C/kg	Lal, R. 2004
Defoliant	6.44 kg C/kg	Lal, R. 2004
Growth Regulator	5.44 kg C/kg	Lal, R. 2004
Methane (Paddy Rice)	620.06 kg C/acre	Tyler 2009

Table 2. Green House Gas (Carbon Equivalent) in Pounds per Acre for Each of the 63 Major Production Methods for the 6 Largest Row Crops in Arkansas

Crop	Production Practice	Carbon Equivalent Emission (lbs/ac)	Crop	Production Practice	Carbon Equivalent Emission (lbs/ac)
Corn	Conventional Center Pivot Loamy Soil	554.62	Sorghum	Center Pivot Loamy Soil	367.44
	Conventional Flood Loamy Soil	474.84		Flood Loamy Soil	326.71
	Conventional Furrow Loamy Soil	477.58		Furrow Loamy Soil	332.45
	BT Furrow Loamy Soil	477.50		Non-irrigated Mixed Soil	247.43
	RR Furrow Loam Soil	492.98			
	RR Furrow Clay Soil	571.07	Full Season Soybeans	RR Non-irrigated	109.04
	BT/RR Furrow Loamy Soil	492.98		Conventional Non-irrigated	89.79
				RR Furrow	220.31
				RR Boarder Irr.	193.26
Cotton	RR Non-irrigated Conventional Till 8 Row	363.30		RR Center Pivot	221.19
	RR Non-irrigated Stale Seed Bed 8 Row	348.32		RR Flood	232.07
	RR Center Pivot Conventional Till 8 Row	514.04		Conventional Furrow	209.07
	BG/RR Center Pivot Conventional Till 8 Row	513.66		Conventional Boarder Irr	174.01
	BG/RR Furrow Conventional Till 8 Row	480.61		Conventional Center Pivot	201.91
	Conventional Furrow Conventional Till 12 Row	479.47		Conventional Flood	212.82
	BGII/RRFlex Center Pivot 12 Row Stale Seed Bed	470.63			
	BGII/RRFlex Furrow 12 Row Stale Seed Bed	455.48	Double Cropped SB	RR Furrow	205.60
	WS/RRFlex Furrow 12 Row Stale Seed Bed	455.18		RR Boarder Irr.	170.55
	RR/Flex Furrow 12 Row Stale Seed Bed	448.46		RR Center Pivot	205.48
	BGII/LL Furrow 12 Row Stale Seed Bed	443.37		RR Flood	202.23
	BGII/RRFlex Furrow No Till 12 Row	456.71		Conventional Furrow	188.45
	BG/RR Center Pivot Stale Seed Bed 12 Row	469.50		Conventional Boarder Irr.	153.40
	BG/RR Furrow 12 Row Stale Seed Bed	455.48		Conventional Center Pivot	188.83
	BG/RR Furrow Conventional Till 12 Row	479.41		Conventional Flood	185.08
	RRFlex Furrow 12 Row Stale Seed Bed	453.48		RR Non-irrigated No Till	75.020
	BGII/LL Center Pivot 12 Row Stale Seed Bed	457.38		RR Furrow No Till	158.89
	BGII/RRFlex Center Pivot No Till 12 Row	477.17		RR Center Pivot No Till	173.15
	LL Furrow 12 Row Stale Seed Bed	440.32			
	BG/RRII Center Pivot No Till Stale Seed Bed 12 Row	477.19	Wheat	Following Rice Sand/Silt Loam Soil	266.27
				Following Rice Clay	284.23
Rice[a]	Conventional Seed Silt Loam Soil	1947.77		Following Other Sand/Silt Loam Soil	242.31
	Conventional Seed Clay Soil	2010.48		Following Other Clay Soil	272.25
	Conventional No Till Silt Loam Soil	1959.07			
	Conventional Seed Stale Seed Bed Silt Loam Soil	1957.87			
	Clearfield Silt Loam Soil	1942.71			
	Hybrid Silt Loam Soil	1905.90			
	Conventional Zero Graded No Till Waterseeded	1858.39			

[a] Rice GHG emissions include the estimated 1,367 lbs of C attributed to methane gas release per acre.

Table 3. Baseline Crop Acerage and Percent Change in State Crop Acerage Given a 5, 10, and 20% Reduction in Statewide Green House Gas Emissions

Crop	State Baseline Acreage	% GHG Reduction from Baseline 5%	10%	20%
Corn (Irrigated)	543,696	1.31	1.80	-73.13
Non-irrigated Cotton	282,055	-22.18	-25.55	-51.39
Irrigated Cotton	586,812	2.72	4.32	-7.23
Non-Irrigated Full Season Beans	728,993	0.52	5.13	42.05
Irrigated Full Season Beans	1,658,700	0.18	0.71	2.20
Irrigated Double Crop Beans	144,800	0.00	0.00	43.42
Rice (Irrigated)	1,464,375	-1.19	-11.49	-13.53
Wheat (non-irrigated)	801,294	1.11	-6.12	-72.13
Non-irrigated Sorghum	109,371	0.03	10.25	-69.34
Hayland	1,409,758	-0.27	-0.51	-32.26
Pasture	2,036,839	-21.01	-21.01	-21.01
Irrigated Sorghum	107,109	7.52	24.50	-73.56
Total Acres in Production	7,836,963	-0.47	-2.23	-18.73
Total Irrigated Acres	4,505,493	-0.37	-2.11	-13.71
Total Carbon Emissions	5,937,312,102	-5.00	-10.00	-20.00
Total Net Returns	656,544,363	-1.83	-5.89	-31.64

Table 4. Baseline County Revuene and Percent Reduction in County Level Agricultrual Revenue Given a 5, 10, and 20% Reduction in Statewide Green House Gas Emissions

		% GHG Reduction from Baseline		
County	Baseline (Million $)	5%	10%	20%
Benton	4.59	7.10	7.10	38.98
Boone	3.44	7.00	7.00	22.40
Carroll	3.52	6.58	6.58	25.65
Madison	3.42	10.18	10.18	35.50
Newton	1.15	12.92	12.92	31.57
Washington	5.06	8.24	8.24	34.38
CRD 1	21.18	8.08	8.08	32.01
Baxter	1.19	15.21	15.21	27.83
Cleburne	1.71	10.55	10.55	37.35
Fulton	3.16	8.90	8.90	22.67
Izard	2.16	14.86	14.86	33.30
Marion	1.71	7.44	7.44	17.57
Searcy	1.99	17.66	17.66	28.56
Sharp	2.12	7.09	7.09	33.41
Stone	1.75	13.56	13.56	42.20
Van Buren	1.49	12.29	12.29	34.18
CRD 2	17.29	11.65	11.65	30.27
Clay	29.96	0.38	1.19	25.89
Craighead	34.09	0.26	0.36	25.90
Greene	19.90	0.89	2.43	24.62
Independence	5.43	8.86	16.85	39.75
Jackson	17.87	0.88	10.11	30.61
Lawrence	20.18	0.44	15.30	16.79
Mississippi	38.38	0.71	5.02	27.20
Poinsett	37.78	0.11	0.47	14.76
Randolph	13.35	2.78	11.11	33.74
White	7.99	7.82	18.61	52.51
CRD 3	224.94	1.08	5.27	25.44
Crawford	2.79	3.93	3.93	25.09
Franklin	2.83	5.13	5.13	43.30
Johnson	1.64	10.26	10.26	53.73
Logan	3.65	5.30	5.30	29.67
Polk	2.01	10.50	10.50	30.62
Pope	2.59	6.72	6.72	34.09
Scott	1.66	4.85	4.85	16.54
Sebastian	1.82	8.48	8.48	42.11
Yell	3.06	10.30	10.30	41.87
CRD 4	22.05	7.04	7.04	34.97
Conway	2.96	4.32	4.32	39.34
Faulkner	4.02	11.01	12.08	23.17
Garland	0.53	23.43	23.43	42.83
Grant	0.59	16.72	16.72	48.86
Hot Spring	0.91	11.40	11.40	37.82
Perry	1.04	5.37	5.37	46.98
Pulaski	2.59	7.54	12.78	48.37
Saline	0.81	18.44	18.44	42.99
CRD 5	13.45	9.65	10.98	37.51
Arkansas	43.02	0.26	0.26	11.57
Crittenden	17.19	0.03	10.53	37.46
Cross	25.89	0.11	12.44	23.39
Lee	20.97	0.29	14.64	62.19
Lonoke	25.80	0.38	0.38	27.47
Monroe	16.44	0.05	2.58	45.55
Phillips	28.26	1.08	4.60	55.25
Prairie	26.27	0.34	0.51	24.46
Saint Francis	18.40	0.31	11.09	36.34
Woodruff	11.64	0.60	3.75	21.53
CRD 6	233.89	0.36	5.41	32.63
Hempstead	3.67	5.86	5.86	29.63
Howard	1.65	5.95	5.95	22.66
Lafayette	2.52	5.16	5.16	39.95
Little River	3.12	3.23	3.23	38.34
Miller	3.78	2.68	10.10	70.99
Montgomery	1.01	5.87	5.87	23.45
Pike	0.96	6.25	6.25	32.99
Sevier	1.76	8.07	8.07	29.05
CRD 7	18.47	4.91	6.43	40.14
Bradley	0.36	8.30	8.30	56.74
Calhoun	0.27	15.20	15.20	49.00
Clark	1.19	8.86	8.86	52.40
Cleveland	0.44	5.85	5.85	51.97
Columbia	0.68	18.93	18.93	32.47
Dallas	0.26	20.63	20.63	47.13
Nevada	1.10	4.94	4.94	32.80
Ouachita	0.41	12.37	12.37	32.51
Union	0.41	8.67	8.67	26.36
CRD 8	5.11	10.25	10.25	41.66
Ashley	8.39	1.27	9.46	36.46
Chicot	20.41	1.19	1.19	41.47
Desha	27.89	0.35	3.11	39.50
Drew	7.01	1.74	25.62	57.92
Jefferson	23.22	0.25	0.25	38.58
Lincoln	13.24	0.81	14.61	32.49
CRD 9	100.16	0.73	5.68	39.79
State Total	656.54	1.83	5.89	31.64

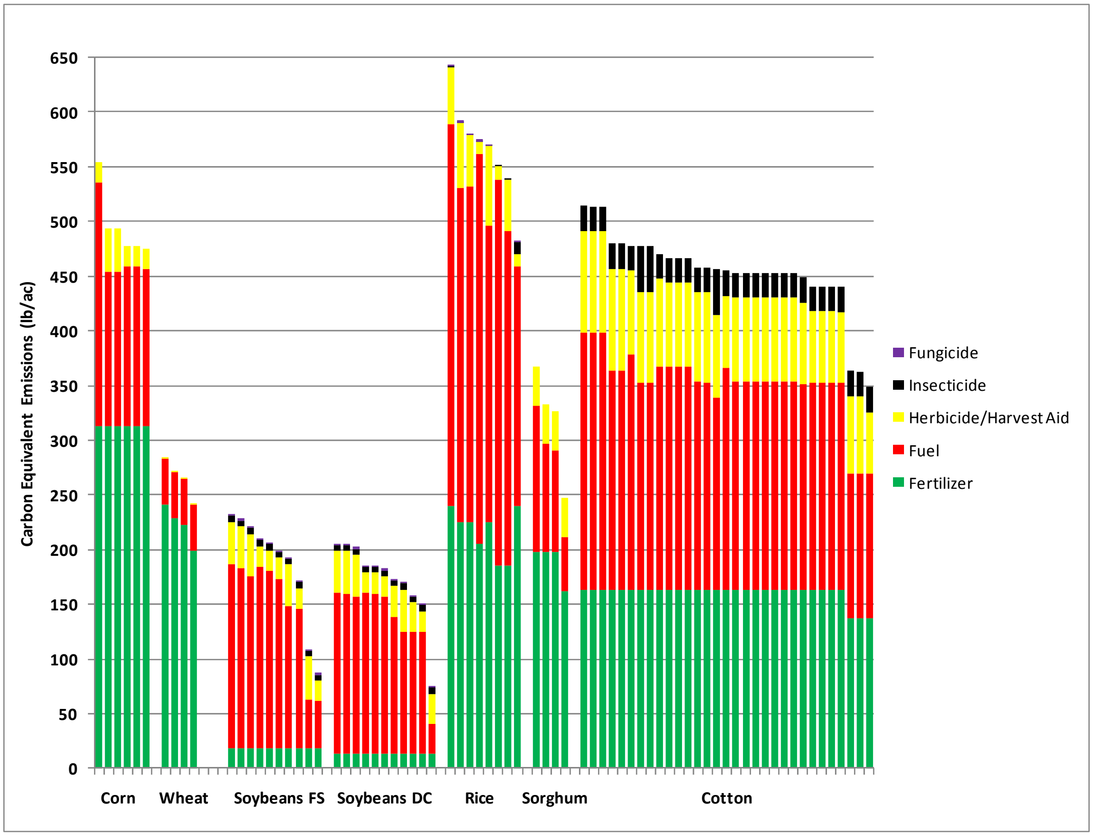

Figure 1. Decomposition of the Total Green House Gas Emission By Crop and Production Types

Note: The Carbon Equivalent for Rice Does Not include the 1,367 lbs Attributed to Methane Release.

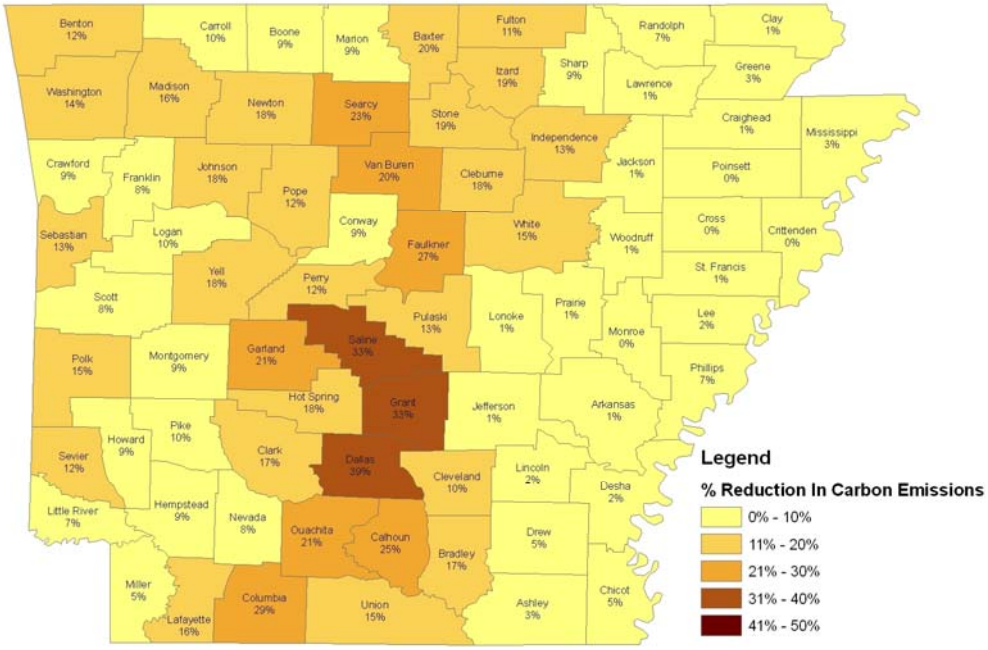

Figure 2. Estimated County Level Agricultral Green House Gas Reduction from a Statewide 5% Cap-and-Trade GHG Reduction Policy

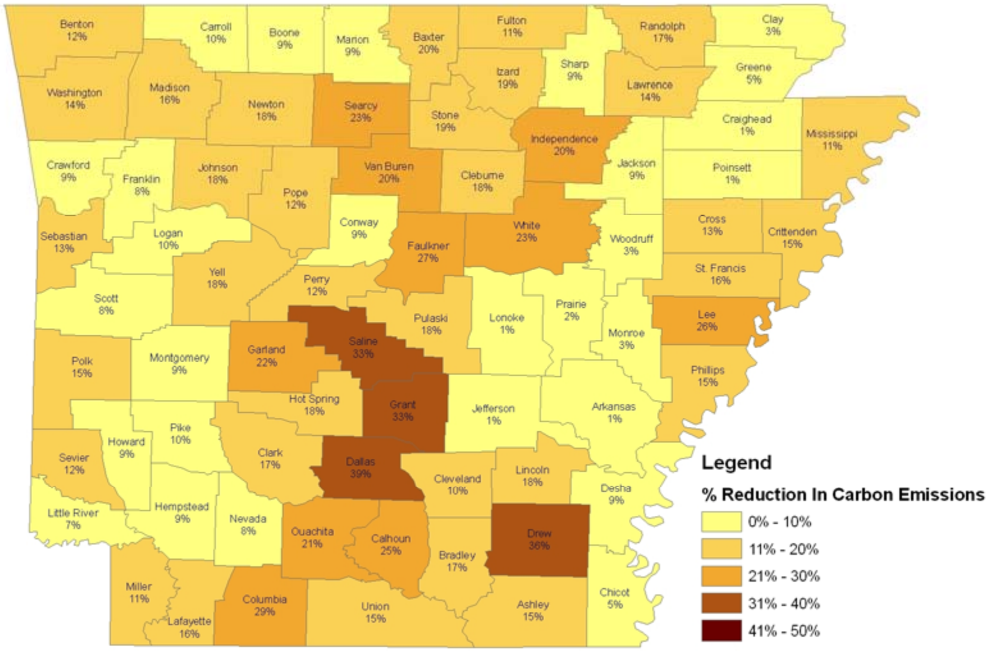

Figure 3. Estimated County Level Agricultral Green House Gas Reduction from a Statewide 10% Cap-and-Trade GHG Reduction Policy

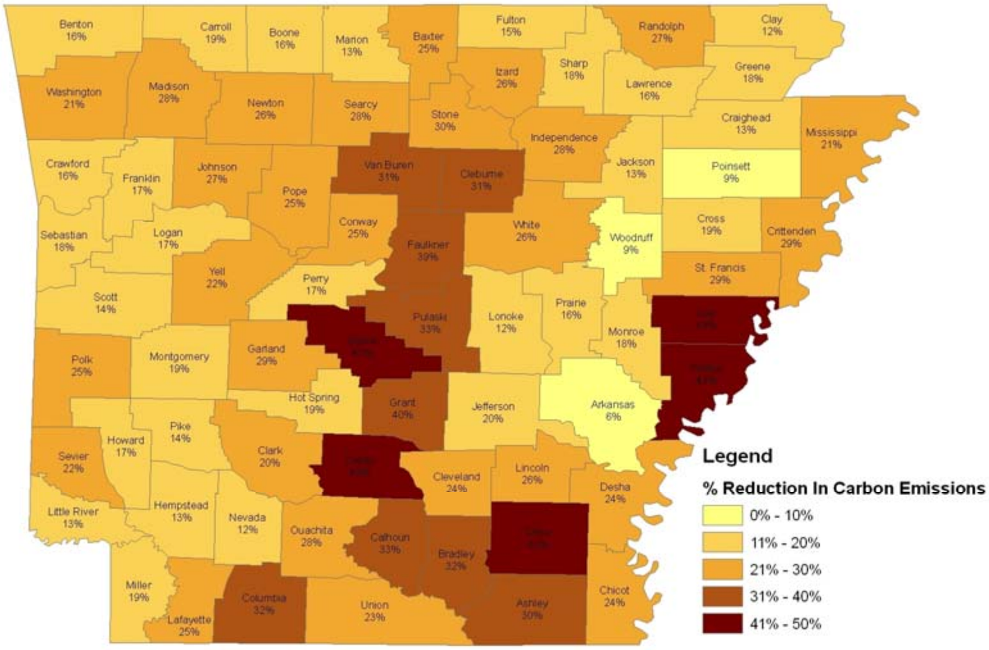

Figure 4. Estimated County Level Agricultral Green House Gas Reduction from a Statewide 20% Cap-and-Trade GHG Reduction Policy