Modeling the Effects of Cap and Trade and a Carbon Offset Policy on Crop Allocations and Farm Income

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Introduction

Given the ongoing discussion about the potential for climate change throughout the U.S., an analysis examining individual state's expectations of cropping pattern changes at the county level is needed. Pressure to reduce green house gas (GHG) emissions coupled with concerns over climate change suggests that policy driven decisions in the form of emissions restrictions or incentive-based carbon offset programs could alter the current face of production agriculture.

Previous research using a scan level lifecycle assessment (LCA) related to Arkansas agriculture has shown that a cap-and-trade program on agricultural GHG emissions would be costly to Arkansas' row crop producer returns if the emissions reductions are greater than 5%.. In addition, GHG reductions greater than 5% would result in nearly equivalent reductions in crop harvested acreage (Nalley et al., 2010).

An incentive-based carbon equivalent offset program, on the other hand, may mitigate the negative income effects by allowing for carbon offset payments to producers for reducing their net carbon foot print (carbon equivalent emissions – soil carbon sequestration). So, rather than accounting only for GHG emissions, the potential for crop production to sequester carbon in the soil as a climate change benefit is added to the LCA. As such, the carbon offset market option compared to a cap-and-trade emissions mandate came at the cost of only minor reductions in GHG emissions from agricultural input use (<1%) while sequestering additional carbon, compared to a baseline, resulting in modest (<5%) net carbon foot print gains due to crop pattern changes at carbon prices as high as $90 per ton (Popp et al., 2010).

Both of the aforementioned scan level LCA analyses were centered on conventional crop production, without, at that time, an alternative carbon sequestering crop. In this study, low-input hay, an activity intended to increase in acreage when land is set aside due to resource constraints such as carbon emissions restrictions, is added. While not profitable at low carbon prices, the activity is expected to increase in value when carbon markets allow for producer payments to lower their net carbon footprint by lowering GHG emissions and at the same time sequestering soil carbon.

The objective of this analysis is thus to estimate how baseline agricultural income and net carbon footprint change from a baseline scenario under profit maximization. Modeled are i) a cap on carbon equivalent emissions on agriculture levied at 5% without payments for carbon foot print reductions with the least profitable land idled to meet emissions restrictions; ii) a scenario where emissions restrictions are enforced but carbon offset payments are made to producers for curtailing emissions and/or enhancing soil carbon sequestration compared to the baseline at $0.20 and $15 per ton of carbon coupled with the introduction of the low-input hay activity; and iii) estimating the carbon price needed to return producer income to pre-GHG restriction levels. The analysis thus demonstrates projected changes in cropping patterns, carbon equivalent emissions and soil carbon sequestration as well as agricultural income effects as a function of various policy alternatives.

<u>Data and Methodology</u>

An existing model (Popp et al., 2010 a) that tracks county level agricultural activity on the basis of relative crop profitability, using a static linear programming framework, was used:

(1) Maximize $NR = \sum_{i=1}^{75} \sum_{j=1}^{12} \left(p_j \cdot y_{ij} - c_{ijn}\right) \cdot x_{ijn}$

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, hay and pasture[1]

where *p, y, c* and *x* are crop price, crop yield, production cost per acre and acreage by county *i*, crop *j* and production method *n*. The model was constrained by historical crop specific ($xmin_{ij}$ / $xmax_{ij}$) and county specific irrigated ($iacresmin_i$ / $iacresmax_i$) and total harvested ($acresmin_i$ / $accresmax_i$) acreage limits to avoid corner solutions where solely the most profitable crop per county would be grown on all acres. These limits reflect socioeconomic and physical barriers to changes in cropping patterns and reflect historical production limitations associated with water availability, land suitability, crop rotation restrictions, producer knowledge and comfort level with production methods, availability of capital and landowner investment in crop specific equipment and/or local value added processing firms.

Once the model was solved for a baseline level of crop, hay and pasture production, a baseline net carbon footprint (C.E. emissions – soil carbon sequestration) was estimated. The model was subsequently modified to not only include an additional enterprise, low-input hay, but also the potential for rewarding producers for reducing their net carbon foot print.

(2) Maximize $$NR = \sum_{i=1}^{75}\sum_{j=1}^{13}\left(p_j \cdot y_{ij} - c_{ijn}\right) \cdot x_{ijn} + \left(BCF_{ij} - (E_{ijn} - S_{ijts}) \cdot x_{ijn}\right) \cdot p_c$$

where BCF_{ij} is the baseline net carbon footprint, E_{ijn} are C.E. emissions by crop, county and production method highlighted in Figure 1, S_{ijts} are estimates of soil carbon sequestration by crop, county, tillage method and soil type highlighted in Figure 2 and p_c is the price of carbon. Note that both figures do not show spatial detail across counties but provide insight regarding

[1] 10% of minimum CRP enrollment acreage from 1997 to 2007 was added as potential for added harvested acre totals in each county to reflect the typical 10-year CRP enrollment period.

range of observations by crop. Details related to parameter estimates used in the model are discussed next.

C.E. emissions

Carbon equivalent emissions (E_{ijn}), as described in Nalley et al. (2010) were estimated on the basis of input use and vary by crop and regional production method *n* (Figure 1). Included in the Nalley et al. (2010) scan level LCA are the carbon equivalent (CE) emissions from the per acre input use of fertilizer, agricultural chemicals and fuel use by each of the 60 production practices and include both direct and indirect GHG emissions up until the farm gate. 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. In contrast, indirect emissions 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. Further, the scope of the analysis was constrained to the production of commodities up to the farm gate. Excluded were emissions generated during drying and transport or processing of a commodity that occurs after the farm gate. Also excluded from this study were 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 excluded those inputs that contributed less than 2% to the total estimated emissions to the farm gate.

Given the 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 US Environmental Protection Agency (EPA, 2007; EPA, 2009) were used for diesel and gasoline combustion emissions and combined with EcoInvent's life cycle inventory database through SimaPro 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 emissions from the soil, which are subject to considerable variation due to timing and method of application of nitrogen as well as climatic and soil conditions, are modeled at 1.27 lb of CE emissions per pound of elemental nitrogen applied. Methane emissions from paddy rice make up a significant portion of emissions and amount to 1,367 lbs per acre of rice (Nalley et al., 2010; Tyler, 2009). Figure 1 indicates that there is considerable variation across crops as well as with respect to inclusion or exclusion of N_2O emissions.

Carbon Sequestration

Using county level yield data and existing literature on harvest indexes (harvested yield/total above ground biomass), shoot to root ratios (total above ground biomass/total below ground biomass) and biomass carbon content information, estimates of above- and below-ground crop-specific amounts of carbon available for soil carbon sequestration could be obtained (Popp et al., 2010b; Prince et al., 2001). Since carbon in the crop residue (e.g. stover, straw, hulls, cobs, etc.) needs to be incorporated in the soil for soil carbon sequestration to occur, different tillage practices affect the amount of above ground biomass that is available for soil carbon sequestration. Further, root matter and incorporated crop residue are subject to microbial decomposition which can lead to some carbon release and more so if the soil is disturbed. Finally, soil texture (clay, loam or sand) impacts a host of soil properties that also impact the potential for carbon sequestration. Table 3 highlights some of the variation in soil types for Arkansas counties whereas Table 4 shows the carbon sequestration factors associated with different tillage methods as they impact above and below ground biomass. For example, a loamy soil is estimated to have the potential to sequester .7 or 70% of carbon available from above and below ground biomass. Using no-till production, only 10% of crop residue is incorporated in the soil due to equipment traffic, and 50% of root matter is sequestered since microbial activity leads to least carbon release with no-till compared to either conventional or low-till production methods. So, if 500 lbs of crop residue and 300 lbs of root matter, both with a 40% carbon content, are produced on a loamy soil using no-till production, only 3.5% (10% added to soil x 50% remains after microbial activity x 70% soil texture effect) of the 200 lbs of C in the crop residue (40% C in the biomass) and 35% (50% remains after microbial activity of material already in the soil x 70% soil texture effect) of the 150 lbs of C in the root matter are sequestered.

Given the static nature of the model as well as low initial soil carbon content in Arkansas soils, dynamics of soil carbon movement within the soil profile as well as carbon saturation in the soil over time are assumed *not* to impact annual sequestration for the foreseeable future (at least 20 years, Brye, 2010). Notable exceptions would be hay and pasture grounds that have already been in lengthy periods of no-till production. Nonetheless, these acres are least likely to change given their low emissions and large carbon sequestration potential to begin with.

Land use alternative

Rather than modeling pine tree production as a carbon sequestering land use alternative (McCarl et al., 2007), a less capital intensive and less risky land use choice, low input hay, was pursued in this analysis. The enterprise involves a moderate level of fertilizer application compared to hay and pasture enterprises, is treated with herbicide for weed control and harvested once per year in June or July to avoid rain related harvesting difficulties at the cost of yielding low-quality hay that could be used for biomass markets or sold as low-quality feed at a discount to conventional hay. This enterprise was developed to capture traditional crop acres forced out of production as a result of a mandated emissions cap. Simulated carbon offset payments make the enterprise increasingly profitable with rising carbon prices and hence a practical land use alternative that commits land to that enterprise for a shorter period of time and with a greater degree of flexibility for livestock production and/or at lower reversion cost to crop land than pine.

Baseline and Scenario Alternatives

The baseline scenario includes the traditional Arkansas row crops of corn, cotton, grain sorghum, rice, soybean, wheat as well as hay and pasture. Pasture returns are modeled at cash rental rates of $21 per acre with carbon footprint estimates including fertilizer, establishment as well as weed and brush control but no emissions related to livestock activities. Conventional hay and low-input hay cost of production were determined on the basis of fertilizer needed for yield potentials of 2.22 and 1.91 dry tons of hay using two and one cuttings, respectively (Huneycutt et al., 1988).

The emissions cap scenario involved the addition of a GHG (carbon equivalent) emissions constraint imposed on Arkansas agriculture as a whole. In essence, the estimate of the sum of all E_{ijn} for the state was multiplied by 0.95 and used as a constraint to be met statewide. Hence, the model solved for the profit maximizing cropping pattern that would solve under the newly imposed emissions reduction.

The carbon offset scenario was added to the emissions cap scenario by compensating producers at different p_c for their net carbon footprint reductions to pay for income losses associated with C.E. emission reductions but now adds potential payment for these emission reductions as well as changes in carbon sequestration as a result of cropping pattern changes. For example, reducing corn enterprise acres, on average the second highest emitter, would now not only reduce emissions but also cost the producer in terms of lost soil carbon sequestration where corn excels (Figure 2).

Finally, the model was solved for the level of p_c needed to offset income losses from a GHG (carbon equivalent) emissions cap. This estimate will reveal the carbon offset price that would be needed for producers to be indifferent to the adoption of a carbon offset policy as modeled within (producer payments from a carbon market for reductions in net carbon footprint from the 2007 baseline scenario).

Results

Table 5 shows changes in crop acreage, state agricultural returns to land and management, and GHG information for the baseline, emissions cap, carbon offset, and income neutral scenarios.

Emissions Cap

Model estimates indicate that wheat, non-irrigated cotton, and rice acres are moved into irrigated cotton, irrigated and non-irrigated grain sorghum and non-irrigated soybeans as the least-cost alternative to meeting the imposed emissions restrictions. This assumes that there is no adoption of technological changes to crop production to reduce GHG emissions without crop pattern changes. Total harvested acreage declines by 3.1%, and the low-input hay activity only picks up moderate acreage as it is not a profitable alternative without carbon offset payments.

While C.E. emissions decline, a portion of the emissions decline is offset by lost sequestration as a result of fewer overall harvested acres and lower corn production (the leading soil carbon sequestering crop modeled). Overall, farm income declines by approximately 2.8% from the unconstrained baseline. Hence, in terms of climate change, an emissions reductions mandate is hampered in effectiveness by a concomitant reduction in carbon sequestration.

Carbon Offset Program

Table 5 highlights the effect of increasing carbon price and the impact of carbon offset payments. At a carbon offset price of $0.20 per ton of carbon, changes in GHG emissions and farm income are negligible compared to the emissions cap scenario. Even at $15 per ton of carbon, an incentive based carbon offset market does little to alter cropping patterns and farm income when compared to the emissions cap. At a price near $100 per ton, however, state farm income returns to pre-emission restriction levels and the incentive based carbon offset payments yielded added soil carbon sequestration that is now larger in tonnage than the mandated emissions reductions (note the increase in corn and hay production). Further, low-input hay takes on 425,000 acres or more than 5% of harvested acreage. Rice, wheat and non-irrigated cotton continue to lose acreage whereas irrigated cotton, irrigated and non-irrigated grain sorghum and soybean gain to increase overall acreage in production.

Conclusions

A static, linear programming framework capable of capturing significant county level detail in terms of spatial changes in production methods and soil types was used to determine impacts of a cap-and-trade emissions mandate as well as potential carbon offset payments in conjunction with an emissions cap. A low-input (low GHG emitting, high sequestering) land use alternative was introduced and proved to gain significant acreage as a result of an incentive based carbon offset policy. Carbon prices need to rise significantly from the current $0.20 per ton for significant changes in cropping patterns to occur. In fact, a cap on emission resulted in lesser soil carbon sequestration by penalizing corn production and lowering overall harvested acreage. Policy implications without consideration of changes in soil carbon sequestration can thus yield counterproductive outcomes.

Drawbacks of the above scenario analyses are that the model operates in a static environment. Neither crop price or production technology changes as a result of cropping pattern changes. It is likely that rice price, for example, would increase to offset production losses or that less, GHG-offensive production methods would be chosen by producers. Results are also subject to considerable uncertainty as parameter estimates surrounding harvest indexes, shoot-to-root ratios and N_2O emissions related to fertilizer application need more ground proofing and/or risk analyses as soil carbon sequestration plays a significant role in climate change mitigation.

Referenced Work

Brye, K. 2010. Personal Communication. Soil Scientist. University of Arkansas, Department of Crop, Soil, and Environmental Sciences.

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

Intergovernmental Panel on Climate Change (IPCC). 2007. "Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].

Lal R. 2004. "Carbon emission from farm operations." *Environment International* 30(7):981-90.

McCarl, B.A. 2007. "Biofuels and Legislation Linking Biofuel Supply and Demand using the FASOMGHG model." Presented at Duke University, Nicolas Institute Conference:

Economic Modeling of Federal Climate Proposals: Advancing Model Transparency and Technology Policy Development, Washington DC.

Nalley, L., M. Popp and C. Fortin. 2010. "The Impact of Reducing Green House Gas Emissions in Crop Agriculture: A Spatial and Production Level Analysis". In Submission. *Northeastern Journal of Agricultural and Resource Economics.*

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

Popp, M., L. Nalley, K. Brye, C. Fortin and A. Smith. 2010b. "A Life Cycle Approach to Estimating Net Carbon Emissions and Agricultural Response to Potential Carbon Offset Policies". In Submission. *Journal of Agricultural and Resource Econmics.*

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

SimaPro 7.1. 2009. Life Cycle Assessment Software, Pré Consultants, Amersfoort, The Netherlands.

Tyler, S. University of California, Atmospherice Science and Biogeochemistry, Irvine, Personal Correspondence sharing experimental data from numerous studies, October, 2009.

United States Environmental Protection Agency (EPA). 2007. Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005. EPA 430-R-07-002. US EPA, 1200 Pennsylvania Ave., N.W. Washington, DC.

United States Environmental Protection Agency (EPA). 2009. Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007. EPA 430-R-09-004. US EPA, 1200 Pennsylvania Ave., N.W. Washington, DC.

Table 1. Carbon Equivalent Emission Factors.

Input	Pounds of Carbon-Equivalent per unit of Input Used	Source
Fuel (gal)		
Diesel	7.01	Sima Pro, 2009, EPA, 2007& 2009
Gasoline	6.48	Sima Pro, 2009, EPA, 2007&2009
Fertilizer (lb)		
Nitrogen	1.30	Lal, R. 2004
Phosphorus	0.20	Lal, R. 2004
Potassium	0.16	Lal, R. 2004
Lime	0.06	Lal, R. 2004
N_2O emissions	1.27	IPCC 2007
Herbicide/Harvest Aid/Adjuvant (pt or lb)	6.44	Lal, R. 2004
Insecticide/Fungicide (pt or lb)	5.44	Lal, R. 2004
Methane (acre of Paddy Rice)	1,367	Tyler 2009

Table 2. Baseline Statistics Using 2007 Crop Input and Output Prices as well as Cooperative Extension Estimates of Production Practices. Numbers are Output Weighted County Averages.

Crop	**Baseline**	**Price**[1]	**Unit**	**Avg. Yield**	**Harvest Index**	**Shoot-Root**	**Carbon Content**[2]		**Avg. Cost**[1]	**Avg. Profit**[1]	**Avg. NCF**[3]
Land type/prod. method	Acres	$		units/acre			Above Ground	Below Ground	$/acre	$/acre	lbs C.E/acre
Rice	1,457,408	9.74	cwt	69	0.45	6.25	0.36	0.35	465.65	206.07	1,601
Cotton		0.62			0.45	4.76	0.42	0.36			
Irrigated	596,357		lb	1,101					613.82	68.72	222
Non-irrigated	282,055		lb	889					490.49	60.54	160
Corn	547,009	3.65	bu	151	0.43	5.26	0.41	0.42	432.62	181.73	(414)
Soybean		6.91			0.45	6.25	0.43	0.43			
Irrigated	1,658,700		bu	41					264.32	16.27	(12)
Non-irrigated	755,203		bu	27					172.65	12.96	(95)
Double cropped	144,800		bu	33					263.66	(29.89)	14
Sorghum		3.64			0.39	12.5	0.42	0.38			
Irrigated	122,394		bu	105					284.59	96.90	(262)
Non-irrigated	109,371		bu	70					187.64	67.30	(130)
Winter Wheat	851,767	4.44	bu	52	0.46	5.56	0.34	0.28	184.04	46.60	150
Hay	1,440,250	60.00	dt	2.22	na	1.00	0.41	0.39	93.50	40.30	(672)
Pasture	3,856,566	21.00	dt	1.17	na	1.00	0.41	0.39	73.23	21.00	(517)
Low-input Hay[4]	-	40.00	dt	1.91	na	1.00	0.41	0.39	80.18	(3.66)	(738)

Notes:

1 Prices are 2007 December futures contract prices for September 2008 delivery with exceptions for winter wheat being the 2007 September futures contract for June 2008 delivery. All prices are net of checkoff, drying and hauling charges. Cost of production includes, seed, fertilizer, herbicides, custom work, fuel, repair and maintenance as well as ownership charges of depreciation and interest for equipment that are prorated over stand lives as necessary. Profit = Yield * Price – Cost. Expect differences due to rounding.

2 Harvest index, shoot to root ratio and carbon content numbers fluctuate widely with averages deemed commensurate for Arkansas conditions reported here.

3 Net carbon footprint are carbon equivalent (C.E.) emissions from input use related to fuel, agricultural chemicals and plastics less soil carbon sequestration from incorporation of carbon in root and above ground biomass. Rice production includes 1,367 lbs of C.E. from methane released under flooded conditions. All emissions numbers are up to the farm gate and exclude drying, transport and storage. Negative numbers therefore imply net carbon sequestration, whereas positive numbers suggest net carbon emissions.

4 Low-input hay is harvested once per year, controlled for weeds and fertilized at an intermediate level between pasture and hay alternatives. It provides a practical alternative for acres idled due to imposed constraints.

Table 3. Average and Range of Soil Texture Adjustment Factors by Soil Texture as Affected by Clayey, Loamy and Sandy Soils in Arkansas.

	Clayey	**Loamy**	**Sandy**	**County Weighted Average Soil Texture Adjustment Factor**
Adjustment Factor	1	0.7	0.4	na
	--- Percentage of All Soils Across Arkansas Counties ---			
Average	9.1	86.7	1.2	0.7
Minimum	0	20.7	0	0.65
Max	68.6	99.8	11.6	0.84

Table 4. Fraction of Carbon Contained in Above- and Below-Ground Biomass Annually Sequestered as a Function of Tillage.

	Sequestration Potential	
Tillage Level	Fraction of Below Ground Biomass	Fraction of Above Ground Biomass
No-Tillage	0.50	0.10
Low- Tillage	0.45	0.40
Conventional	0.40	0.70

Table 5. Summary of Income, Acreage, Net Carbon Footprint and Irrigation Water Use as a Result of Potential C.E. Emissions Cap and Carbon Offset Markets.

	Baseline (in 000s)	**Emissions Cap**	**Offset** $0.20	**Offset** $15.00	**Offset** $98.87
Acres					
Rice	1,457	-5.6%[a]	-5.6%	-5.6%	**-7.8%**
Cotton					
Irr	596	5.7%	5.7%	**5.9%**	**10.3%**
Non-irrigated	282	-11.5%	-11.5%	-11.5%	**-25.7%**
Corn	547	-0.8%	-0.8%	-0.8%	**0.4%**
Soybean					
Irr	1,659	0.7%	0.7%	0.7%	**0.6%**
Non-irrigated	755	17.5%	17.5%	17.5%	**8.1%**
Double cropped	145	-	-	-	-
Sorghum					
Irr	122	16.8%	16.8%	16.8%	**18.6%**
Non-irrigated	109	11.0%	11.0%	11.0%	**8.0%**
Wheat	852	-42.8%	**-43.0%**	**-43.1%**	**-47.0%**
Hay	1,440	0.6%	0.6%	0.7%	**1.8%**
Pasture	3,857	-	-	-	-
Low-input Hay	-	20[b]	**23**	**29**	**425**
Total Harvested Acres	7,965	-3.1%	-3.1%	**-3.0%**	1.0%
Total Irrigated Acres	4,527	-0.4%	-0.4%	-0.4%	**0.4%**
GHG (tons of C.E./yr)					
Emissions	3,039	-152[c]	-152	-152	-152
Soil Carbon Sequestration	3,436	-35	**-34**	**-30**	**155**
State Returns ($/year)	696,467	-2.79%	**-2.78%**	**-2.53%**	0.00%

Notes:

[a] Percentage change compared to the baseline.

[b] Thousands of acres added compared to the baseline.

[c] Change in thousands of tons compared to baseline.

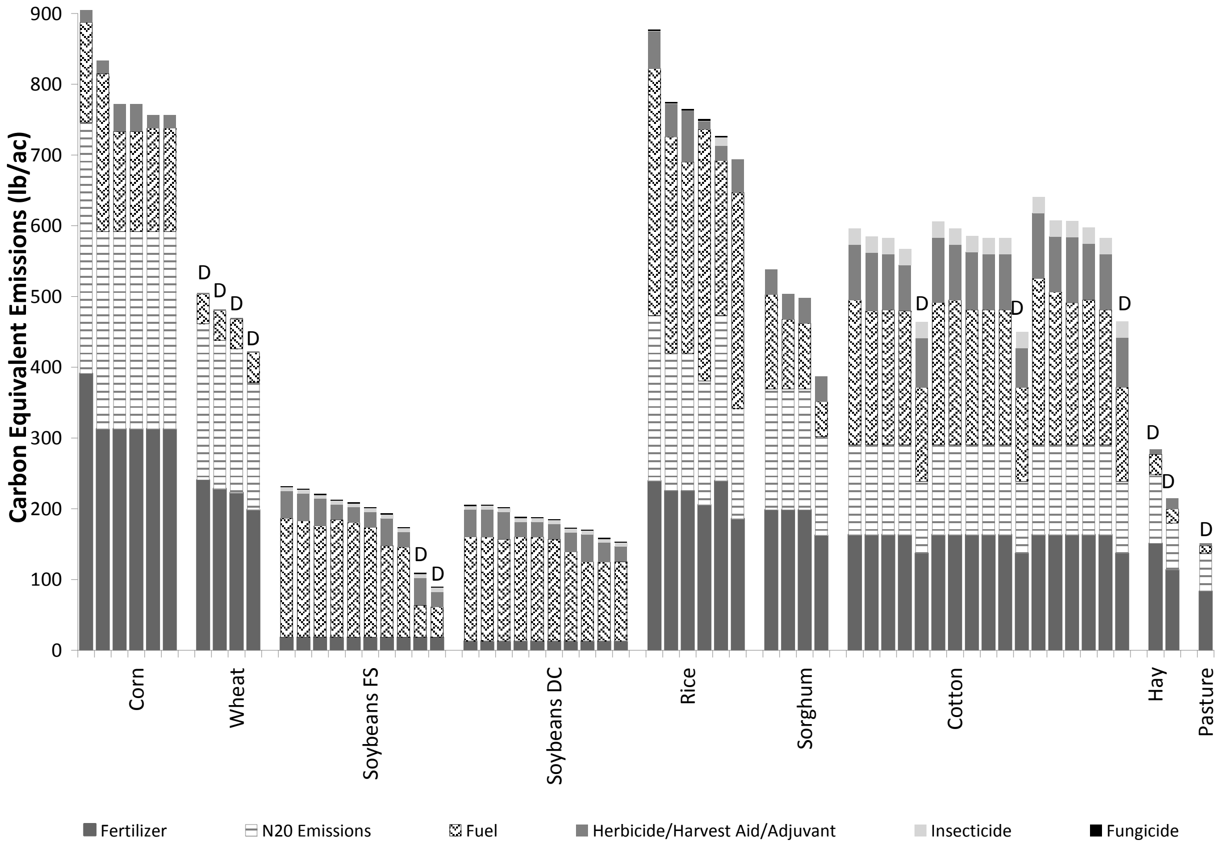
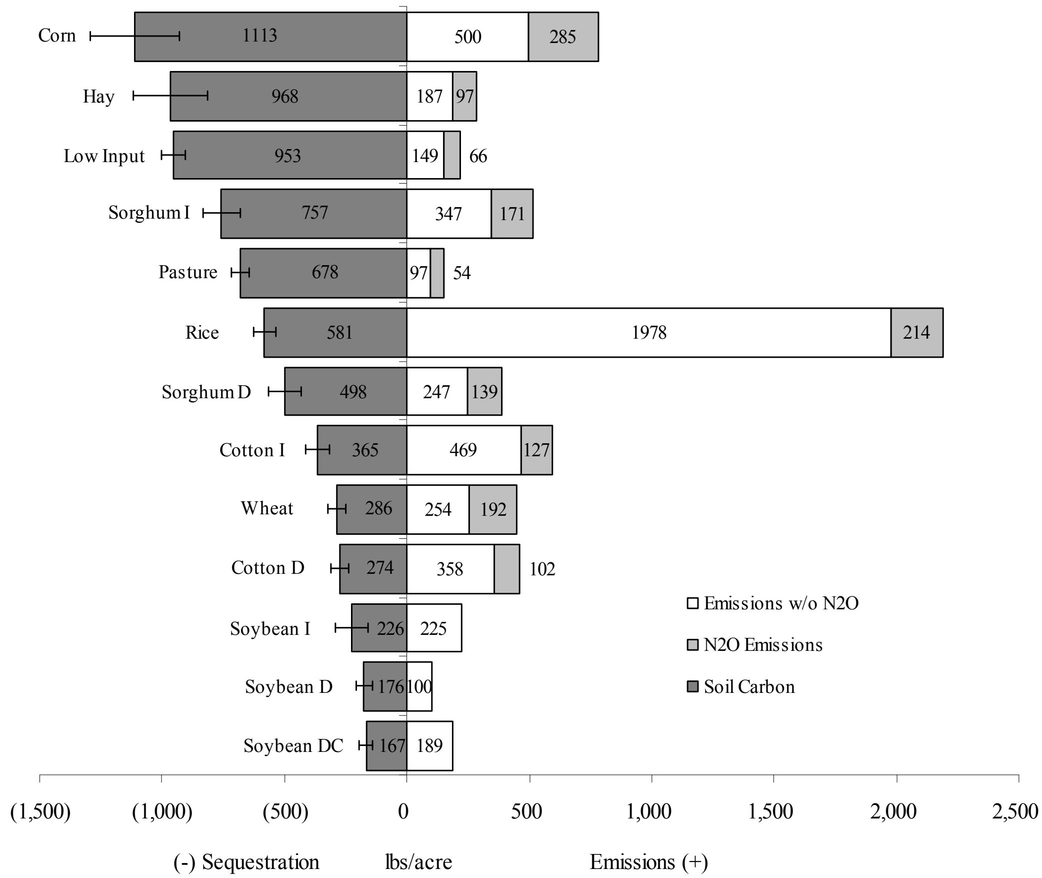


Figure 1. Decomposition of the Total Green House Gas Emission By Crop and Production Types

Note: The Carbon Equivalent for Rice does not include the 1,367 lbs attributed to methane release. D symbolizes non-irrigated enterprises.

Figure 2. Carbon Equivalent Emissions (E_{jn}) and Sequestration (S_{ijts}) by Crop Including Variation in Carbon Sequestration Due to Yield, Soil and Tillage Effects. Numbers are Simple Averages across All Counties.



Notes: I = irrigated, D = non-irrigated/dryland, DC = double cropped. Error bars on the sequestration side include variation due to yield, soil type and tillage effects but exclude expected variation in harvest index and root to shoot ratio. Also note that soybean production entails no nitrogen fertilizer application and hence no N_2O emissions. Additional uncertainty, especially pertaining to N_2O emissions exists and is not shown here. For further detail on emissions see Nalley et al. (2010).