How a National Carbon Policy Could Affect Grain Variety Selection: The Case of Rice in Arkansas

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Introduction

The pressure to lower carbon emissions is increasing given increased consumer awareness and demand for "green" goods, industry pressure from companies like Wal-Mart for their suppliers to lower their overall greenhouse gas (GHG) emissions, and potential government policy in the form of a cap-and-trade or an offset program. The American rice industry has recently come under scrutiny for the amount of water usage and total GHG emissions released in production. Rice, like many other agricultural products, actually sequesters CO_2 from the atmosphere during production. While there have been many studies on the impact of a carbon policy on national cropping patterns (Reilly, 2009; Outlaw et al., 2009; Beckman et al., 2009; McCarl, 2007) and studies that estimate cropping changes within states (Nalley et al. 2010; Nalley and Popp, 2010) there has been very little research on how a potential government policy or increased consumer demand for lower GHG emissions in agricultural products could affect the varietal selection of crops. Ridgwell et al. (2009) suggested that selecting different cultivars of the same crop species to maximize solar radiation reflexivity could cool the planet and producers could potentially receive carbon credits. However, there seems to be a void in the literature analyzing the emissions by cultivar of the same crop and how cultivar selection could be altered by a carbon policy. This study attempts to fill this apparent gap in the literature by addressing how a climate change policy that internalizes costs of GHG emissions to producers would affect cultivar choice when subject to a carbon tax or a carbon payment.

Given the recent introduction of hybrid rice in the mid-south, a carbon policy may add further reason to adopt the technology as yield premiums over conventional cultivars lead to input efficiencies that concomitantly lead to environmental benefits by way of reduced GHG emissions per bushel of rice. Hybrid rice can yield 15-20% more than conventional cultivars under the same growing conditions with roughly the same input requirements. This study estimates a net carbon footprint (GHG emissions from input use – soil carbon sequestration from residue and roots) for 14 of the most commonly sown rice cultivars in Arkansas in six locations throughout the Delta. The cultivars include conventional, Clearfield, and hybrid cultivars. The results should provide information to producers, millers, and buyers about the relative difference in GHG emissions by cultivar so they can adapt to a potential carbon tax/offset policy or to changes in consumer demands for "green products".

This research has global implications since roughly half of the world's population consumes rice daily with 10.2% of global exports provided by the U.S. in 2009 (Childs and Baldwin, 2010), of which nearly half was supplied by Arkansas rice producers. Changes in estimated GHG emissions per acre as a result of cultivar-specific input requirements across type of rice (Clearfield, conventional, and hybrid) produced differently across six counties in Arkansas provided information for Monte Carlo simulation to model uncertainty in production parameters. The results thus provide potential insight into producer response to rice varietal selection if a carbon offset or carbon cap/tax policy is implemented. Results are also important to large rice buyers who could potentially start evaluating cultivars from a sustainability perspective.

Life Cycle Inventory

The Life Cycle Inventory (LCI) used within included both direct and indirect emissions associated with rice production. Direct emissions are those that come from on-farm operations. Examples are carbon dioxide (CO_2) emissions from diesel used by tractors and irrigation equipment and gasoline used by farm trucks. Indirect emissions are generated off farm as a result of manufacturing inputs used on the farm. Examples are GHG emissions from natural gas to produce commercial fertilizer. Excluded from this study are embedded carbon emissions as a result of upstream production of equipment and tools used on farm for agricultural production. Nitrous oxide (N_2O) emissions from application of nitrogen fertilizer were included in estimations of GHG. While methane (CH_4) emissions are the largest contributor to the total GHG emissions in paddy rice production they were not included in this study. The rationale being, that at the time of this study, there were no methane emissions studies conducted for the Delta of Arkansas. The EPA has produced figures for the US rice industry as a whole but given the highly sensitive spatial differences in methane emissions by soil type, fertilizer application method and residue management, the void of data for methane emissions in Arkansas resulted in its exclusion.[1] Nonetheless, there are unpublished studies for Texas and Louisiana that were considered but finally excluded on the advice of agronomists that think that these regions would not serve as a good proxy given differences in climate, soil profiles, crop rotations and nitrogen fertilizer applications.[2]

Carbon emissions calculations

In essence, multiple GHG's associated with global warming, were converted to their carbon equivalent (CE) to obtain a "carbon footprint" -- a process stemming from a rich

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[1] The number of days on flood is the largest factor in methane emissions in rice. Once reliable methane emissions per day have been estimated for flooded rice they can be multiplied by the cultivar specific days on flood requirements to calculate a CE. Further research on this topic is warranted.

[2] Louisiana water seeds a good portion of their rice, whereas Arkansas producers predominately drill seed followed by a delayed flood, which would result in less days on flood and less methane emissions. In previous studies, a proxy of methane emissions equivalent to 1,367 pounds of carbon equivalent per acre was used under the assumption of an average of 84 days of flooded conditions. Further, since these emissions are not expected to vary significantly across use of conventional vs. hybrid technology cultivars with similar flood requirements, inclusion would likely affect cultivar differences only modestly.

engineering literature on CE. Values provided by the US Environmental Protection Agency (EPA) were used for diesel and gasoline combustion emissions (Table 1). EcoInvent's life cycle inventory database through SimaPro (2009) 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_2O) emissions from soil have been identified as a major contributor to greenhouse gas emissions from crop production (Bouwman, 1996; Smith, 1997; Yanai, 2003; Del Grosso et al., 2005; Snyder, 2007). The IPCC (2007) Third Assessment Report conversion factor of 298 units CO_2 per unit of N_2O (or 81 units CE) was used based on a 1 percent loss from nitrogen application rates. A process-based method for estimating N_2O such as DAYCENT (Del Grosso et al., 2005), as opposed to a general emissions factor would reduce N_2O emission uncertainty, but the data input with spatial resolution required for such an analysis were out of the scope of this study. Nonetheless, given the level of uncertainty with respect to N_2O, using regional emission factors from a process based model such as DAYCENT would be an appropriate next step in further refining the analysis. Further, although different types of nitrogen fertilizer (e.g. ammonium nitrate or urea) require different amounts of energy, we use a generic N_2O CE emission value because of the large uncertainty in climatic conditions and variance within a farm.

Annual estimates of cost of production for four major production methods of rice by the University of Arkansas Cooperative Extension Service (UACES, 2008a) are reported for different soils, production regions and production practices commonly used by producers. These cost of production methods are then disaggregated so that they can represent the cost of production for the 14 most commonly produced rice cultivars throughout Arkansas. Using the carbon equivalents from Table 1 and the recommended input usage for each of the 14 cultivars, a per acre GHG emission level could be calculated for each cultivar by location similar to Nalley et al. 2010.

Total carbon emission per acre simply indicates the amount of GHG emitted and not the efficiency of or benefit derived from each unit of GHG. By dividing the total GHG by the mass of rice harvested on each acre, an efficiency measure per unit of rice can be established. That is, while CE per acre is an important measure, in particular as a baseline to compare changes over time, CE emitted per bushel of rice is a better measure for comparing impacts from production across space and time with respect to GHG emissions efficiency.

Cultivar Specific Production Information

The 2008 estimates of cost of production for four of the most common rice production methods (Clearfield, Clearfield hybrid, conventional on silt loam, and hybrid) put forth by the UACES were used as a baseline to create cultivar-specific costs of production. The baseline production methods were modified to reflect the different production requirements of each cultivar. For instance, to quantify the GHG emissions necessary to mitigate blast, a rice fungus, it was necessary to translate the meaning of the rather broad terms put forth by the UACES of "susceptible, moderately susceptible, resistant and moderately resistant" into different levels of fungicide applications across cultivars. Several University of Arkansas plant pathologists were asked for their expert opinion on the probability of applying a Quadris fungicide application to mitigate blast for each of the rice cultivars in the study. In this sense the probability of a disease outbreak was associated with the genetic level of blast tolerance that each cultivar possessed.

Table 2 illustrates how the 14 rice cultivars and their associated probabilities of requiring either one or two Quadris treatments were classified to mitigate a blast outbreak. These probabilities allow estimating the quantity of Quadris required in an average growing year by cultivar, and the estimated amount of fuel to apply it via a crop duster.[3] Thus, a cultivar specific GHG emissions estimate can be approximated for each cultivar to mitigate blast. As shown in Table 2, hybrid cultivars are more blast resistant than conventional and Clearfield cultivars and hence show lower GHG emissions per acre. Table 2 also illustrates the differences within the conventional cultivars with respect to blast resistance. This same methodology was used to calculate the GHG emissions associated with mitigating sheath blight and smut by cultivar.

Cultivar specific nitrogen fertilizer recommendations were gathered from the UACES recommended application rates ranging from 120 to 150 lbs/acre.[4] Diesel/petrol usage was calculated by summing the amount of fuel required for cultivar specific irrigation levels, fungicide applications and fertilizer applications (via crop duster), pesticide applications, herbicide applications, as well as standard fuel usage for planting and harvesting. The irrigation levels (acre-inch) by cultivar were provided from the UACES and ranged from 30 for conventional and hybrid cultivars to 36 inches/acre for the Clearfield cultivars. Clearfield cultivars require more water due to their susceptibility to blast, which can be controlled with a deeper flood. The study assumed that water for irrigation was pumped from 100 feet using a

[3] Since crop dusters vary by engine size and nozzle type three crop dusting companies were surveyed from the Arkansas Delta and their associated fuel usage by acre were used to simulate fuel use per acre using a triangular distribution.

[4] These amounts represent the total amount applied, both early (pre-flood) and mid-season applications. These are the recommended amounts for silt loam soils following a soybean rotation which was the most prevalent practice in 2009 at 68% of the acres (Norman and Moldenhauer, 2009).

diesel pump which required 1.022 gallons of diesel to raise one acre-inch of water (Slaton 2001).[5]

Even though the UACES puts forth recommendations for fertilizer, fungicide, pesticide, and water usage, producers often will use more or less of a given input given seasonal growing conditions. That is, producers may apply more nitrogen as insurance against uncertainty of nitrogen deficiency (Babcock, 1992). To account for variation in recommended and actual input use, rice experts from the University of Arkansas (a soil chemist in the case of nitrogen) were asked to estimate minimum and maximum levels of input application. Thus a range of input use was created by cultivar. This methodology was used for fertilizer, fungicide, herbicide, pesticide, and water usage and is illustrated in Table 3. All cultivars have a mean carbon footprint as well as an estimated probability density function.

The Clearfield cultivars (CL151, CL171, and CL181) require the largest average fuel usage (Table 4) due to elevated irrigation requirements due to their susceptibility to both blast and sheath blight which also requires more fungicide applications. However, the three Clearfield lines also require the least herbicide per acre since producers can use the herbicide Newpath for efficient control of red rice (Table 4). Red rice is a persistent problem for rice producers in the Southeast and was estimated to be present in approximately 20% of all rice acreage in Arkansas in 2002 (Annu et al. 2005). Its dark kernel color requires costly separation during the milling process. Also, its nearly identical genetic structure to commercial rice means that no existing herbicide could adequately control red rice without also injuring or killing conventional rice.

[5] Assuming a 75 percent pump efficiency and 5 percent drive loss. Aquifer depth is assumed to be equivalent across the counties in the study.

Clearfield lines, however, allow the use of Newpath for control of red rice and hence they have a major advantage.

The hybrid cultivars (XL723, XL729, and XL745), all released by Rice-Tec, use the least fungicide, and thus less fuel, given their resistance to blast and only moderate susceptibility to sheath blight. Two of the hybrid cultivars (XL729 and XL 745) contain the Clearfield trait, but the Clearfield cultivars (CL151, CL171, and CL181) are not hybrids. Hybrids are the F_1 seeds of a cross between two genetically dissimilar parents which results in a yield increase of 15-20% more than the best inbred cultivar grown under similar conditions (Virmani et al. 2003). Since hybrid offspring (F_2) generally do not perform as well as their parents (F_1), producers must purchase fresh seeds each growing season. Given the difficulty and costs of producing hybrid seeds, the cost of seed to producers is the highest of the three types of rice at approximately $88 per acre compared to $42 and $18 per acre for Clearfield and conventional cultivars, respectively in 2009.

Carbon Sequestration Calculations

As in Nalley and Popp (2010), using a methodology similar to Prince et al. (2001), pounds of carbon sequestered from above ground biomass (*ABG*) per acre for rice cultivar *j* in test plot *i* can be estimated by:

(1) $$AGB_{ij} = \left[\left(Y_{ij} \cdot \lambda_j \cdot (1 - \alpha_j) \right) \cdot \left(\frac{1}{H_j} - 1 \right) \cdot \beta_j \cdot \delta \cdot \eta \right]$$

where Y_{ij} are experiment station level yields in bushels per acre, λ_j converts yield to lbs per acre, α_j is the moisture content of the grain harvested so that yields can be converted to dry matter yields, H_j is the harvest index, β_j is the estimated carbon content of above ground biomass, δ is the estimated proportion of above ground biomass incorporated in the soil as a function of conventional tillage and η is the estimated fraction of plant residue in soil contact that is sequestered in the soil.[6] Note that all above ground residue (rice straw) is assumed left on the field and not burned.

Pounds of carbon sequestered from below ground biomass (*BGB*) per acre for rice cultivar *j* on test plot *i* can be estimated by:

(2) $$BGB_{ij} = \left[\chi_j \cdot \eta \cdot \left(\frac{\varphi_j \cdot \left[Y_{ij} \cdot \lambda_j \cdot \left(1 - \alpha_j \right) \right]}{H_j} \right) \right]$$

where χ_j is the carbon content of below ground biomass and ϕ_j is the shoot to root ratio with the other variables as defined above. Thus total carbon sequestration S_{ij} per acre for cultivar *j* in county *i* under conventional tillage on primarily silt loam soils can be estimated by:

(3) $$S_{ij} = \left(ABG_{ij} + BGB_{ij} \right) \cdot \xi$$

where ξ is a soil factor that adjusts carbon sequestration potential based on soil texture (Nalley and Popp, 2010).[7] Harvest indices, root to shoot ratios, carbon contents of above and below ground biomass are reported in Table 5. Crop residue soil incorporation due to conventional tillage is estimated at 70% (δ), with 40% (η) of carbon content in both above and below ground residue potentially sequestered in the soil. Finally, silt loam soils are textured such that only an estimated 70% (ξ) of potentially sequestered carbon remains in the soil with the remainder escaping to the atmosphere (Brye, 2010).

[6] The harvest index is the ratio of dry matter yield to total dry matter produced above ground. Per the extension budgets, conventional tillage was used in estimations.
[7] The soil factor for silt loam was used in estimations presented.

Yield Data

Yield data were collected from the Arkansas Rice Performance Trials (ARPT) test plots throughout the Delta of Arkansas from 1997-2009 (UACES, 2010b). The ARPT data consist of four university-run experiment stations, Pine Tree (St. Francis County), Stuttgart (Arkansas County), Rohwer (Desha County), and Keiser (Mississippi County), and two test plots conducted by farmers in Jackson (Ahrent Farm) and Clay (Ruteldge Farm) counties. A total of 14 cultivars were tested from 1997-2009. The cultivars included eight conventional cultivars (four from the University of Arkansas and four from Louisiana State University), three hybrid cultivars released by Rice-Tec, and three Clearfield cultivars. Table 6 provides the average yield for each variety across all locations in the study.

Modeling Uncertainty

Quantitative uncertainty analysis is not new to environmental life cycle assessment, but it is not well adopted (Lloyd and Ries, 2007). Quantifying variability and uncertainty for this analysis was performed using Monte Carlo simulation (Hujibregts et al., 2001). For our initial analysis we used mean values for all of our input data in our model. However, there is significant variability and uncertainty in these numbers. For example, there is uncertainty in how much carbon emission actually comes from the burning of fuel, either to run tractors, or to produce inputs. Additionally, there is both uncertainty and variability in the amount of inputs used in production. There may be variability for a farm either across fields or years, or variability between farms. Uncertainty can potentially be overcome with more extensive data collection or model revision. Variability cannot be overcome in modeling, but only through the standardization of production practices. That being said, given the differences in pumping depths for irrigation, input usage as a function of producer risk aversion, and climatic and agronomic differences throughout the production region high variability in practices do exist and must be accounted for. Table 3 illustrates the simulated parameters and their associated means and range.

Results

Table 6 shows that nitrogen fertilizer associated N_2O emissions as well as diesel fuel used for flooding the field accounted for the majority of carbon emissions. Given their susceptibility to blast and thus their increased water requirements, Clearfield lines used more diesel (Table 4) than other cultivars. Diesel fuel accounted for an average of 49% of Clearfield's carbon footprint while accounting for approximately 41% of the carbon footprint of other cultivars. Conversely, since the Clearfield lines require less nitrogen fertilizer (Table 4), fertilizer and N_2O play a smaller role in Clearfield's total emissions. Table 6 also presents the average yield per acre for each of the cultivars across all test plots. The hybrid cultivars averaged 9,421 lbs per/acre (209 bu/acre), the conventional cultivars 7,969 lbs/acre (177 bu/acre), and the Clearfield cultivars averaged 7,803 lbs/acre (173 bu/acre). Using the yield data, pounds of carbon sequestered could be estimated under the assumption of a constant harvest index implying higher biomass production with higher yields. On average, the hybrid cultivars sequestered the most carbon at 813 lbs/acre, followed by the conventional cultivars at 690, and the Clearfield cultivars at 673 lbs/acre.

Emissions per Acre and Pounds of Rice/Pound of Carbon

While carbon emissions and sequestration per acre are pertinent information when addressing total carbon emissions, they lack economic relevance in the form of input use efficiency. That is, a per acre measurement does not indicate which cultivar has the highest yield per unit of GHG emissions. The ratio of carbon emissions per bushel of rice produced is a direct measure of GHG use efficiency that can be used on a comparative basis across time and space. Table 7 show both the net (emissions – sequestration) carbon footprint per acre as well as the average CE per bushel of rice for each cultivar across locations. There is large spatial variation across test plot location and within cultivars. Some cultivars (Bengal, Cocodrie, Cheneire, Taggart, Templeton, and CL181) were estimated to be net emitters across all locations.[8] No cultivars were estimated to be net sequesters across all locations. Nonetheless, the hybrid cultivars XL723 and XL729 were net sequesters in all locations except Desha county where yields were 17% and 30% lower than the average across other plot locations. Although the Clearfield lines (CL151, CL171, and CL181) use on average 62% less herbicide than the hybrid cultivars they typically yield less (21% on average). This results in the ratio of lbs CE/bu favoring the high yielding hybrids and mitigating the Clearfield reduction in herbicide application.

Given their high yields (Table 6) and their high levels of sequestration the hybrids have the most favorable lbs CE/bu ratio. In Arkansas County, the largest rice producing county in Arkansas, XL729 is estimated to sequester approximately 122 lbs CE/ac and has an estimated yield of 9,606 lbs/acre (214 bu/ac), compared to the most popular rice cultivar in the state Wells, which was estimated to emit 108.59 lbs/CE per acre and yield 7,881 lbs/ac (175.14 bu/ac). A similar trend holds true for XL723. In every county it has a lower net carbon footprint than any conventional or Clearfield cultivar.

Carbon Policy Effects on Planting Decisions

[8] Bengal, Cocodrie, and Cheneire were released by Louisiana State University and may fare better in Louisiana.

While the Waxman-Markey Bill failed to pass the Senate in 2009, it brought political attention to carbon reduction policies via a cap and trade type system. Under a cap and trade policy a set percentage reduction from a baseline emission level would be implemented. Given that rice is the largest row crop GHG emitter in the United Sates it would stand to reason that rice acreage would decrease if agriculture was subject to cap and trade (Nalley et al. 2010). Under a cap and trade policy those producers/ regions /cultivars which have the highest profit per pound of carbon emitted ($/ lb of C) would be relatively advantaged. Figure 1 illustrates that within a county there are statistically significant differences in the lbs of CE/bu ratio. For example, in Arkansas county XL729 had the lowest lbs of CE/bu ratio at 3.33 compared to Taggart at 5.01lbs CE/bu. Ignoring other crops that could vie for rice acreage, this would indicate that under a cap and trade policy that solely targets reduction of carbon emissions, rice producers in Arkansas county, for example, would theoretically reduce acreage of Taggart before acreage of XL729 given the disparity in lbs of CE emissions/bu ratio.[9] Further, if it is assumed that input price changes occur to the same extent regardless of rice production region and the price of rice does not vary significantly across cultivars, then the largest driver in the $/lb of C ratio across time is yield. Figure 1 illustrates the fact that for Arkansas County, the three hybrid cultivars (XL723, XL729, and XL745) had the lowest lbs CE/bu ratio, largely driven by yield.[10] Hence, those counties/cultivars with relatively high rice yields, namely hybrids, look to be better positioned to handle an emissions reduction policy.

[9] This assumes that all producers have the same supply elasticity and does not take into consideration preferences for hybrid vs. conventional, medium vs. long grain, need for Clearfield technology, or other varietal characteristics. It also assumes that all cultivars possess the same end use qualities for milling, puffing, parboiling etc. This is often not the case.
[10] This is true for the other five locations analyzed in the study.

Given the unlikely implementation of a cap and trade policy, alternative policy measures include an incentive system for net carbon footprint reduction. In this study, a carbon offset market is modeled where producers could sell net carbon footprint (emissions – sequestration), not total carbon sequestered, and only if sequestration is greater than emissions per acre. Importantly, this distinction from the cap and trade policy does not ignore how much carbon is sequestered from the atmosphere during that production. Hence production practices/cultivars are rewarded with a carbon payment/permit as long as carbon sequestration exceeds emissions. Thus a carbon offset policy, if adopted as discussed here, is more comprehensive than a cap and trade system as it not only tracks emissions but also takes into account regional and production practice differences in C sequestration.

Again, Table 7 shows the emissions and net emissions per acre and per bushel of rice produced from the six test plots, respectively. Unlike the cap and trade type system where only *CE* emissions and yield produced were the determining factors on which cultivar to use, in the offset policy the ratio of net *CE* emissions and yield are the driving factors. As with the cap and trade policy it appears that the hybrid cultivars, driven mainly by superior yield, would be the benefactors of an offset policy (Figure 2). However, even with the largest estimated sequesterer in the study, XL723 in Clay County at 278.24 lbs of carbon sequestered per acre, at current Chicago Climate Exchange (CCX) price of $0.10 per ton of carbon this would equate to an offset payment of only $0.01 per acre. Hence, little incentive exists at current carbon prices to switch cultivars and even with a relatively high carbon price of $30 per ton this would only equate to a payment of $4.17 per acre.[11]

Overall then, it is likely that a market based carbon offset incentive would be insufficient for producers to change cultivars. Nonetheless, as companies like Wal-Mart and Kellogg's strive to lower their overall carbon footprint, and consumers demand more environmentally "friendly" products there may be upstream pressure to change cultivars.

Conclusions

This study set out to estimate the amount and variability of carbon-equivalent GHG emitted and the amount of carbon sequestered from 14 commonly produced rice cultivars on a carbon per bushel basis for six locations across the Arkansas Delta. From these estimates, spatial and cultivar comparisons are made to project how a potential carbon policy could affect rice producers in Arkansas. These estimates are also important given the rise in consumer demand for "green" products and industry demand for a reduction in their overall carbon footprint.

Cultivar specific input requirements were collected for 14 cultivars across six locations to analyze emissions and sequestration differences. Using a LCA, carbon was estimated for both direct and indirect emissions. Carbon emissions were estimated per acre as well as per bushel of rice at the side of the field. Nitrogen fertilizer was the largest component of GHG emissions, due

[11] Further, this payment would more than likely not occur once methane is accounted for in the estimation of net carbon footprint. Should the concept of additionality (where payments are based on changes in carbon footprint rather than ability to net sequester) be used in this study instead, however, the carbon offset payment rests on relative footprint across cultivars. While this would increase the level of payments, it would still be a relatively minor factor for cultivar selection. For example, the largest difference in net carbon footprint across cultivars in a particular county occurs in Clay county. A difference in carbon footprint of 529 pounds between CL 171 (emitting 280 lbs per acre) and XL723 (sequestering 249 lbs per acre) equates to an advantage for switching from Clearfield to hybrid rice of $0.03 and $7.94 per acre at $0.10 and $30.00 per ton of carbon, respectively.

to the energy required to produce nitrogen fertilizer as well as soil N_2O emitted from its application. Diesel fuel used for irrigation was the second largest component of total GHG emitted.

This study empirically highlights the differences between a cap and trade policy and an offset policy on rice varietal selection. From a cap and trade policy standpoint, the ratio of CE/bu appears to be the driving factor in which cultivars will experience a loss/addition of rice acreage. Intuitively, one would think those cultivars with the lowest GHG emissions per acre would experience an increase in adoption if a cap-and-trade policy would be implemented. However, some rice cultivars (the hybrid XL745) have high levels of inputs (nitrogen fertilizer), but also have a relatively high yield, and so the GHG emissions per bu of rice is much closer to the overall mean of lower-input and low-yielding conventional cultivars. In this manner, cap and trade will not necessarily reduce acreage of those cultivars with the highest inputs but rather reduce acreage in those counties with the lowest profit/yield per unit of carbon released. This would imply that the hybrid cultivars with their high yield, and low CE/bu would stand to fare the best under a cap and trade type policy.

From a carbon offset standpoint, the estimates generated in this study do not indicate, even under high carbon prices, that an offset market will change varietal selection by producers at current carbon prices. When comparing the potential of direct on-farm effects of carbon policies on rice producers it appears that a cap and trade type policy will have an impact. Given that rice is the largest emitting per acre row crop produced in the United States, it is likely that acreage would decrease given a cap and trade policy that includes agriculture. Which acreage/cultivars will be reduced is a function of profitability/yield per unit of GHG emitted.

This study found that some of the hybrid cultivars had a net reduction by 623 lbs/ac over the conventional cultivars.[12] Thus, it would appear that consumer and industry demand for “greener” products and/or a cap and trade type policy that included agriculture could ultimately affect which rice varieties producers sow in the mid-south rice growing region.

While the estimates of emissions by production type are relatively straightforward, estimating sequestration will prove more problematic with a larger margin of error (soil texture, harvest index, shoot to root and tillage parameters are all based on expert opinion with little verified Arkansas information available and none used for methane in this study). Even still, a carbon offset policy, especially with additionality, leads to producer signals favoring high-yielding, low input rice cultivars. Without mandated carbon footprint reduction either by government or via imposed restrictions by retailers, a carbon offset payment/permit system is likely to lead to lesser cultivar change given small estimated incentives for switching. Further research highlighting the uncertainty in emissions and more so, sequestration, as well as an investigation of various definitions of carbon offset policies should prove useful for further policy insights.

[12] This advantage will likely remain after methane is accounted for, since days on flood is the main driver of methane emission and the hybrid varieties have fewer days on flood than conventional cultivars.

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Table 1. Carbon Equivalent Emission Factors

Input	Carbon-Equivalent	Source
Fuel		
Diesel	7.01 lbs C/Gal	USA EPA 2007 &2009, Sima Pro
Gasoline	6.48 lbs C/Gal	USA EPA 2007 &2009, Sima Pro
Fertilizer		
Nitrogen	1.30 lbs C/lb	Lal, R. 2004
Nitrogen N_2O	1.27 lbs C/lb	IPNI 2007, IPCC 2007
Phosphate	0.20 lbs C/lb	Lal, R. 2004
Potash	0.16 lbs C/lb	Lal, R. 2004
Herbicide	6.44 lbs C/pt	Lal, R. 2004
Insecticide	5.44 lbs C/pt	Lal, R. 2004
Fungicide	5.44 lbs C/pt	Lal, R. 2004

Table 2. Genetic Blast Tolerance by Cultivar and Respective Probabilities of Quadris Applications

Cultivar	Blast Susceptibility Rating [a]	Probability (%) of One Quadris Application [b]			Probability (%) of Two Quadris Applications		
Conventional		Min	Mean	Max	Min	Mean	Max
Wells	Susceptible	1	5	10	0	2	5
Francis	Very Susceptible	5	15	25	1	10	20
Bengal	Susceptible	1	5	15	0	2	5
Jupiter	Susceptible						
Cocodrie	Resistant	0	0	0	0	0	0
Cheniere	Susceptible	2	5	10	0	0	0
Taggart	Susceptible	1	6	15	0	2	5
Templeton	Resistant	0	0	0	0	0	0
Clearfield							
CL-151	Very Susceptible	10	25	40	5	20	35
CL-171	Moderately Susceptible	0	0.5	1	0	0	0
CL-181	Moderately Susceptible	0	0.5	1	0	0	0
Hybrid						0	0
XL 723	Resistant	0	0	0	0	0	0
XL 729	Resistant	0	0	0	0	0	0
XL745	Resistant	0	0	0	0	0	0

[a] Susceptibility ratings provided by the UAECS, 2010b.

[b] Recommended Quadris application is 12.5 oz/acre if there is a blast outbreak. Thus, in an average growing year, Francis would require 3.125 (0.15*12.5+ 0.1*12.5) oz/ac. Given the fungicide CE in Table 1 this would be equivalent to 1.004 lbs of carbon (3.125/16 *5.44).

Table 3. Range and Modeled Values for Input Usage Per Acre by Cultivar

Input	Min	Mean	Max	Modeled Value[a]
Fertilizer (lbs/ac)				
Wells/ Francis/ Bengal/ Jupiter/ Cocodrie/ Cheniere/ Taggart/ XL 745	142.50	150	172.50	155
Templeton/CL 171/CL 181	128.25	135	155.25	139.50
CL 151/ XL 723/ XL 729	114	120	138	124
Fuel (gal/ac)				
Crop Duster	0.32	0.50	0.60	0.47
Fungicide (pts/ac)				
Blast	Varies by reported varietal susceptibility			
Sheath Blight				
Herbicide (pts/ac)[b]				
2, 4-D	0	0.20	2.50	0.90
Aim EC	0	1.50	8.80	3.43
Beyond	0	5	6	3.37
Command	0	0.80	1.60	0.80
Facet	0	0.25	0.67	0.31
Permit	0	1	1.30	0.78
Propanil	0	6	8.10	4.71
Newpath	0	8	12	6.67
Insecticide (pts/ac)				
Insecticide	0.025	0.10	0.35	0.16
Number of Applications per Acre by Crop Duster				
Fertilizer	2	2.10	2.70	2.27
Fungicide	Varies by varietal			
Herbicide	1	1.50	2	1.50

[a] Values were estimated using a triangular distribution.

[b] Herbicide use varies by variety, per UACES, 2010 a.

Table 4. Average per Acre Input Requirements by Cultivar on Silt Loam Soils

Cultivar	N (lbs/acre)[a]	Fungicide (pt/acre)[b]	Herbicide (pt/acre)	Diesel (gal/acre)[c] [d]	Irrigation (in/acre)	Days on Flood
Conventional						
Wells	150	0.29	6.76	46.29	30.66	85
Francis	150	0.37	6.76	46.33	30.66	85
Bengal	150	0.15	6.76	46.20	30.66	90
Jupiter	150	0.37	6.76	46.33	30.66	82
Cocodrie	150	0.35	6.76	46.32	30.66	90
Cheniere	150	0.40	6.76	46.35	30.66	86
Taggart	150	0.21	6.76	46.24	30.66	88
Templeton	135	0.14	6.76	46.19	30.66	88
Clearfield						
CL151	120	1.20	2.56	53.73	36.80	82
CL171	135	1.03	2.56	53.63	36.80	85
CL181	135	0.99	2.56	53.61	36.80	85
Hybrid						
XL 723	120	0.08	6.76	46.06	30.66	83
XL729	120	0.08	6.76	46.06	30.66	82
XL 745	150	0.14	6.76	46.09	30.66	77

[a] Summation of preflood and midseason nitrogen application. Nitrogen rate recommendation for rice following soybeans.
[b] Summation of fungicide used to mitigate blast, sheath blight, and smut .
[c] Summation of diesel used in tractors, crop dusters, and diesel irrigation pumps.
[d] Assuming a required 1.022 gallons of diesel to raise an acre inch of water.

Table 5. Values Used in Carbon Sequestration Estimates

Variable	Value	Reference	Modeled Value
Crop Residue Carbon Content (β)			0.36
	0.33	Witt et al. (2000)	
	0.35	Campbell et al. (2001)	
	0.40	Choudhury (2001)	
Harvest Index (H)			0 .45
	0.31	Ottis and Talbert (2005)	
	0.43	Slaton (2010)	
	0.45	Bufogle et al. (1997)	
Root Carbon Content (χ)			0.35
	0.35	Campbell et al. (2001)	
	0.35	Witt et al. (2000)	
Root to Shoot Ratio (Φ)			0.16
	0.15	Slaton (2010)	
	0.18	Yoshida (1981)	

Table 6. Average Carbon Emission and Yield per Acre by Cultivar and Inputs on Silt Loam Soils Across the Six APRT Test Plots

	Greenhouse Gas Emissions (lbs/acre)						
Cultivar	Diesel[a]	Fungicide, Herbicide & Pesticide	Fertilizer[b]	N_2O[c]	Total Emissions (lbs/acre)	Total Sequestration (lbs/acre)	Yield (lbs/acre)
Wells	324	45	228	197	794	686	7,920
Francis	325	45	228	197	794	727	8,391
Bengal	324	44	228	197	793	689	7,960
Jupiter	325	45	228	197	795	789	9,113
Cocodrie	325	45	228	197	795	687	7,936
Cheniere	325	45	228	197	795	664	7,669
Taggart	324	44	228	197	793	636	7,342
Templeton	311	44	208	177	740	642	7,420
CL 151	377	23	187	157	745	747	8,658
CL 171	376	22	208	177	783	622	7,209
CL 181	376	22	208	177	783	651	7,543
XL 723	323	44	187	157	712	773	8,961
XL 729	323	44	187	157	712	834	9,661
XL 745	323	44	228	197	792	832	9,642

[a] Sum of diesel used for tractors and for irrigationapplied.
[b] Sum of N-P-K application.
[c] From nitrogen fertilizer application

Table 7. Varietal Carbon Footprint for Counties with Arkansas Rice Performance Test Plots

County	Wells	Francis	Bengal	Jupiter	Cocodrie	Cheniere	Taggart	Templeton	CL 151	CL 171	CL 181	XL 723	XL 729	XL 745
Arkansas	108.59[a]	67.83	103.39	5.71	107.41	130.97	157.51	97.08	-2.30[a]	160.90	131.73	-61.33	-121.72	-39.86
	(0.62)[b]	(0.36)	(0.58)	(0.03)	(0.61)	(0.77)	(0.97)	(0.59)	(-0.01)[b]	(1.00)	(0.79)	(-0.31)	(-0.57)	(-0.19)
Clay	-35.63	-10.99	10.88	-6.24	108.07	6.10	157.51	97.08	NA[c]	-64.49	NA	-278.24	NA	NA
	(-0.17)	(-0.05)	(0.05)	(-0.03)	(0.61)	(0.03)	(0.97)	(0.59)		(-0.30)		(-1.09)		
Desha	135.20	87.2	120.46	111.05	173.84	195.17	133.99	154.62	231.47	344.79	310.68	19.71	117.66	334.62
	(0.80)	(0.48)	(0.70)	(0.63)	(1.09)	(1.27)	(0.79)	(1.03)	(1.75)	(3.06)	(2.56)	(0.11)	(0.77)	(2.84)
Jackson	-20.90	-55.64	33.29	-132.49	19.97	13.41	87.90	243.67	NA	279.73	NA	-249.08	NA	NA
	(-0.10)	(-0.26)	(0.17)	(-0.56)	(0.10)	(0.07)	(0.49)	(1.91)		(2.16)		(-1.01)		
Mississippi	58.53	37.46	134.28	111.19	168.49	101.60	167.81	23.24	140.18	154.29	131.02	-3.25	-212.07	118.76
	(0.31)	(0.19)	(0.79)	(0.63)	(1.05)	(0.57)	(1.05)	(0.13)	(0.90)	(0.95)	(0.78)	(-0.02)	(-0.89)	(0.68)
St. Francis	44.01	-30.47	64.34	27.01	120.57	78.11	130.76	158.75	109.42	283.12	217.58	-7.88	-75.79	96.11
	(0.23)	(-0.14)	(0.34)	(0.14)	(0.70)	(0.42)	(0.77)	(1.07)	(0.67)	(2.20)	(1.50)	(-0.04)	(-0.37)	(0.54)

[a] Carbon footprint (emissions – sequestration) measured in pounds of carbon equivalent per acre. A positive value indicates a net carbon emitter and a negative value indicates a net carbon sequesterer.

[b] Carbon footprint measured in pounds of carbon per bushel.

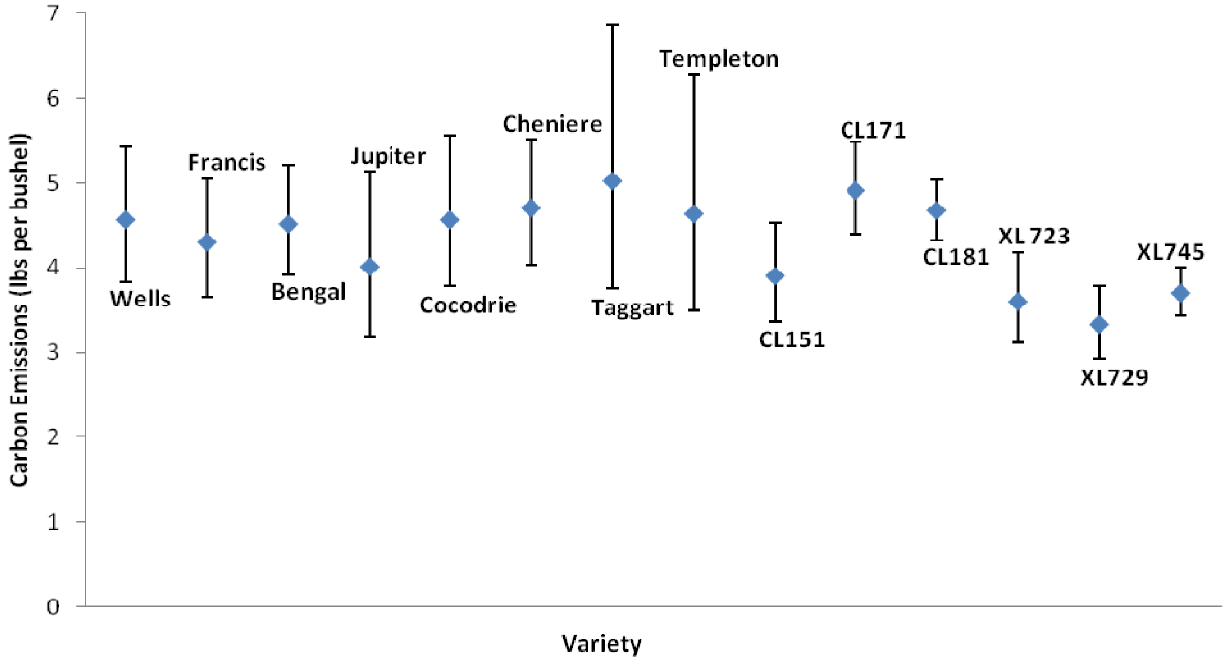

Figure 1. Average and 90% Confidence Interval of Carbon Equivalent Emissions Per Bushel of Rice in Arkansas County, Arkansas

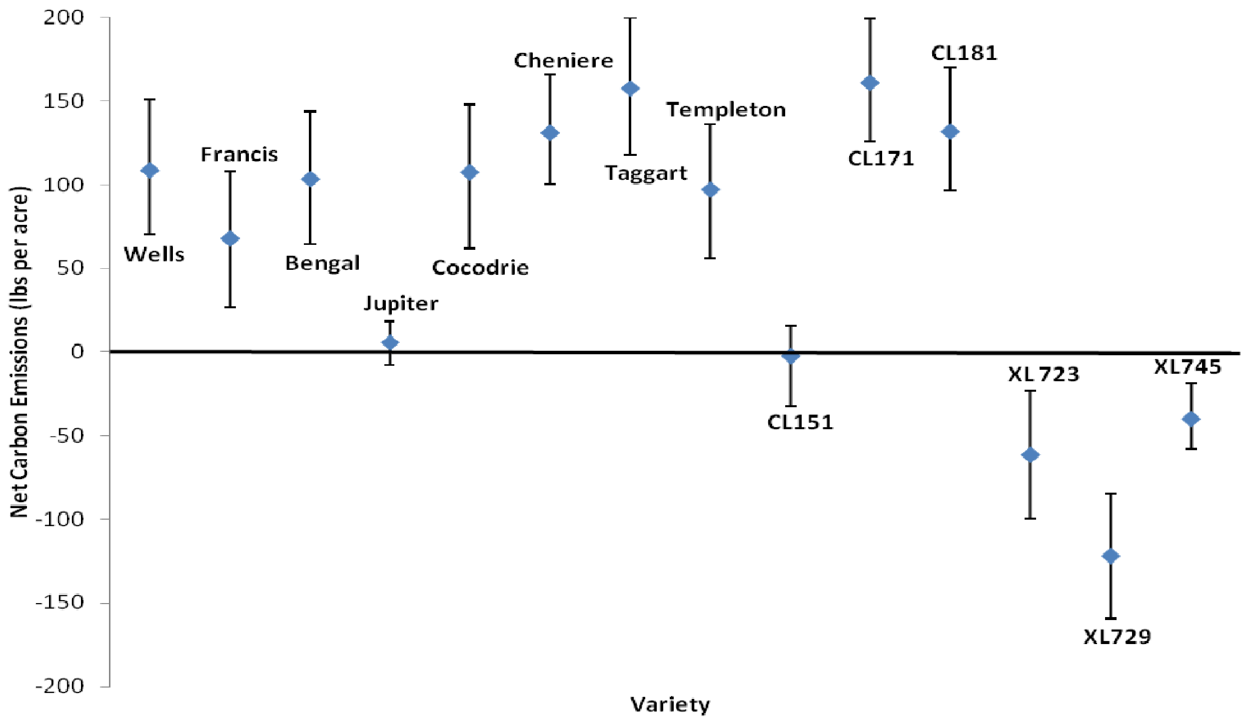

Figure 2. Average and 90% Confidence Interval of Net (Emissions – Sequestration) Carbon Equivalent Emissions Per Acre of Rice in Arkansas County, Arkansas