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# **The Economic Viability of Alternative Wet Dry (AWD) Irrigation in Rice Production in the Mid-South**

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## **Abstract**

This study looks at the economic feasibility of Alternate Wet Drying (AWD) irrigation methods to address concerns of groundwater depletion and greenhouse gas (methane) emissions associated with rice production. AWD is an irrigation régime where the producer allows the rice field to dry intermittently during the rice life-cycle rather than having the field continuously submerged. In previous studies AWD has been found to reduce water usage by from 20-70% and to reduce methane emissions by over 50% as compared to rice produced under continuous flooding. However; the large disadvantage of AWD is that it is often times associated with a yield loss. Thus, this study sets out to estimate the economic viability of three types of AWD irrigation methods in Arkansas using test plot data. Data includes water usage, methane emissions and yields for three hybrid rice varieties across three years and three AWD methods. The goals of this study are to (1) estimate if any of the AWD methods demonstrate higher profitability than traditional flooding (2) introduce a carbon offset market to capture benefits of the GHG reduction, via methane, and estimate profitability between AWD and traditional flooding (3) introduce a water tax equivalent to the social cost of water and reestimate profitability of AWD and traditional flooding. These results will give producers as well as large rice buyers (MARS and Kelloggs) an idea of relative profitability and additional premiums necessary to switch to/source a more “sustainable” rice crop.

## **Introduction**

We assess the economic feasibility of Alternate Wet Drying (AWD) irrigation methods to address concerns groundwater depletion and greenhouse gas (GHG) emissions (principally methane) associated with rice production. AWD is an irrigation régime where the producer allows the rice field to dry intermittently during the rice life-cycle rather than having the field continuously submerged. In previous studies AWD is found to reduce water usage by from 20-70% and to reduce methane emissions by almost 50% as compared to rice produced under continuous flooding, which was certified by the Intergovernmental Panel on Climate Change (IPCC). However; the large disadvantage of AWD is that it is often times associated with yield loss. Thus, this study sets out to estimate the economic viability of three types of AWD irrigation methods in Arkansas using test plot data.

Groundwater depletion in the rice producing region of Arkansas is a pressing concern. Today's irrigation level is unsustainable in the sense that water use exceeds recharge. In 2004, the Arkansas Natural Resources Commission (ANRC) estimated groundwater withdrawals at 6.5 billion gallons per day, a 70% increase from the amount used in 1985 and over twelve times that of 1945 (ANRC, 2007). Exacerbating this issue is the drilling of over 10,000 new wells since 1997 (ANRC, 2007), which is likely a result of enhanced profitability for irrigated crops (notably corn) as well as agricultural lending preferences for irrigated production. To reach sustainable pumping levels, the United States Geological Survey's 2013 estimates indicate that certain rice growing counties in the Arkansas Delta counties will need to reduce irrigation pumping rates by as much as 74% (USGS, 2013). With water supplies declining at these rates in parts of the Alluvial aquifer, water-intensive agricultural production and associated processing industries are at risk.

Figure 1 illustrates the percentage of irrigation water use that is sustainable in counties located in the Alluvial aquifer region. These estimates are based on 2009 pumping rates, the most recent sustainability study of its kind put out by USGS. Arkansas, Lonoke, Lee, Poinsett and St. Francis counties would all need to reduce their pumping rates by over 40% to maintain current ground-water levels. To put this in perspective, these counties alone consisted of 25% of Arkansas' total rice acreage in 2012. Hogan et al. (2007) estimated that flood irrigation for an acre of rice required more than twice as much irrigation water as the methods used with other crops in the Mid-South. From rice production in Arkansas alone from 2000 through 2009, based on harvested cropland acres from USDA-NASS (2010), required an average of 3.6 billion m<sup>3</sup> of irrigation water per year. This presents a problem for sustainability given the profitability of rice combined with the required water needed for its production.

Besides using nearly twice as much water as the next crop produced in the state, rice production (from seed to farm gate) has been identified as a significant source of atmospheric methane (CH<sub>4</sub>) emissions from U.S. agricultural production (U.S. Environmental Protection Agency, 2011). As a result, producers and large purchasers of U.S. rice have attempted to increase the GHG emissions efficiency of rice production. Since 2007, the California Rice Commission has worked with the Environmental Defense Fund (EDF) to reduce the CH<sub>4</sub> emissions associated with California rice production. Best management practices for GHG reduction developed by the partnership might allow California rice producers to participate in voluntary carbon offset markets (Lyman and Nalley, 2012). The EDF has since partnered with Arkansas based Winrock International to extend the product to Arkansas (Bennett, 2011). Kellogg, a large purchaser of U.S. rice, is working with Louisiana rice producers to increase the sustainability of Kellogg's rice-based supply chain (Schultz, 2011). Mars, another major

purchaser of U.S. rice, recently hired a rice scientist to assist Mars' sustainability effort (Mars, 2011). Increasing pressure on rice producers to reduce their GHG emissions will likely have significant implications for Arkansas, home to nearly half of U.S. rice production.

The goals of this study are to (1) estimate if any of the AWD methods demonstrate higher profitability than traditional flooding (2) introduce a carbon payment from an offset market for GHG reduction, via methane, and estimate profitability between AWD and traditional flooding (3) introduce a water tax equivalent to the social cost of water and reestimate profitability of AWD and traditional flooding. We data on water usage, methane emissions and yields for three hybrid rice varieties across three years and three AWD methods. These results will give producers as well as large rice buyers (MARS and Kelloggs) an idea of relative profitability and additional premiums necessary to switch to/source this "sustainable" rice crop.

### **Alternate Wet Dry Rice Production**

Alternate Wet-Dry (AWD) irrigation is an irrigation scheme where the producer allows the rice field to dry intermittently during the rice life-cycle rather than having the field continuously submerged. The theory behind AWD is that this irrigation method allows the roots of the rice plant to be adequately supplied with water for some period (due to the initial flush or flooding) even if there is no observable standing water in the field. The rate and timing of the application of the water is determined by the producer and is a function of rainfall, soil type and the specific period of the rice life-cycle. Theoretically AWD can increase the water use efficiency by reducing seepage and percolation during production.

Previous studies in the mid-south have concluded that rice could be produced under non-flooded conditions using furrow and sprinkler irrigation are not economically viable (Van der Hoek et al. 2001). Those authors found that rice yields under non-flooded conditions generally

decreased proportionally with reduced water application (increased stress). There were periods during the rice growth cycle when the yield was particularly sensitive to moisture stress. However, they also found that there were statistical differences in yield among different varieties and their resistance to both blast and drought stress. Vories et al. (2002) reported consistently lower yields with furrow irrigation of rice than for flooded production. Studies with center pivot systems during the 1980s in Louisiana (Westcott and Vines, 1986) and Texas (McCauley, 1990) reported large yield and revenue reductions compared with flooded production. Other studies (Guerra et al. 1998 and Bouman et al. 2000) have shown that test plots using water-saving irrigation techniques (AWD) have the potential to reduce total water usage by 20-70% without causing significant yield losses. That being said, these were test plots, under highly controlled environments where scientists could precisely control the flushing of the fields given different stages in the rice life cycle minimizing stress on the plant. The most comprehensive study, a synthesis of 31 published articles, conducted by Bouman and Tuong (2001) found that 92% of the AWD studies resulted in yield reductions ranging from zero to 70% relative to flooded controls. The authors state that the large range in yield reductions is due to the differences in “severity” of AWD treatments, ranging from marginal water savings with little stress on the rice crop to significant water savings associated with large yield penalties. In most of the mid-south where flooding predominates, failure to maintain an adequate flood depth results in dry portions of the paddy leads to increased weed pressure and lower yields. Another large obstacle for mass adoption in the Mid-South is the presence of rice blast and the fact one of the most efficient ways of mitigating an outbreak is simply raising the flood on a field, which cannot be done with AWD or center pivot irrigation.

### *Disease Issues with Alternative Irrigation*

Rice blast is one the most frequent and costly diseases of rice in the Mid-South, caused by the fungus (*Magnaportha grisea* ). The fungus survives between crops on infected rice straw/seed. Blast lesions typically form as oval-shaped spots on rice leaves with these lesions producing spores that are transported through the air to other plants where they continue the infection process throughout the growing season if climatic conditions are favorable. At heading (the emergence of the panicle tip from the flag leaf sheath), spores can infect the node below the panicle, resulting in “neck blast” the most damaging type of blast. The yield losses associated with blast outbreaks in Arkansas have been estimated from 10 to 50% (Delta Farm Press 2004).

Fungicides have been produced worldwide to help control blast, most notably with Quadris® and Quilt® in the United States,. When blast lesions are found, via scouting, fungicide is quickly applied via crop duster in an attempt to mitigate the spread of the disease. However, the use of fungicides with similar modes of action over extensive periods is not recommended because this results in the emergence of resistant populations of the pathogen (Kim et al 2008). Given that producers historically plant varieties with weak blast resistant they have relied on raising the flood to mitigate blast outbreaks. Since AWD irrigation methods typically do not involve flooding, blast possess a serious impediment for the wide scale adoption of AWD.

In the past decade, the increased availability of hybrid rice seed in the mid-southern United States has offered rice producers an alternative to the inbred (conventional) rice cultivars historically planted in the mid-south. The heterosis or vigor, of first-generation (F1) hybrid rice (can yield 15 to 20% more than conventional cultivars on similar land due to the combination of yield-improving genetic traits from parent cultivars (Yuan and Virmani, 1988). Arkansas, the largest rice producer in the United States, accounts for two-thirds of the total hybrid rice acreage



in the mid-southern states (Louisiana, Mississippi, Missouri, and Texas). Hybrid adoption in Arkansas has grown from 2% of harvested long-grain acreage in 2002 to nearly 50% in 2011. Producers in Arkansas have also adopted hybrids because of their increased disease package; all hybrids are blast resistant.

In the late 1990's center pivot rice production was tried on some fields throughout the Arkansas Delta with little success. Producers experienced reduced yields attributed to the fact they could not control weeds as efficiently as with a flood and the presence of blast. At that time there were only a few rice varieties that were completely blast resistant and the only way to mitigate a blast outbreak was to either spray fungicide or raise the flood (which was not an option for center pivot rice). So, until recently with the mass adoption of hybrid varieties and a few conventional (inbred) varieties (namely Roy J) any type of alternative irrigation systems AWD or center pivot have not been seriously considered by producers. Thus, with the advent of hybrids and Roy J this study sets out to see what if any economic benefits are associated with the environmental benefits that come with AWD irrigation methods using blast resistant varieties.

#### *Greenhouse Gas Reduction Potential with AWD Irrigation*

Methane is produced anaerobically by methanogenetic bacteria and flooded rice fields are the second largest source of methane emissions after ruminant livestock. Methane is over 21 times more potent in terms of greenhouse warming potential than CO<sub>2</sub> over a 100-year period (EPA, 2014). Methane emissions from rice fields are determined mainly by water regime (flooding or alternative irrigation methods) and organic inputs, but they are also influenced by soil texture, weather, tillage management, residues, fertilizers, and rice variety. Flooding of the soil is a prerequisite for sustained emissions of methane. Periodic aeration of flooded soils inhibits methane producing bacteria; as such AWD can substantially reduce methane emissions.

Wassmann, Hosen and Sumfleth, 2009 estimate that AWD irrigation can reduce methane emissions by over 40%. Lampayan (2012) and Wassmann et al. (2009) showed that AWD has the potential to reduce methane emissions by almost 50% as compared to rice produced under continuous flooding, which merited certification from the Intergovernmental Panel on Climate Change (IPCC). In the revised IPCC methodology (IPCC 2006), “multiple aeration,” to which AWD corresponds, is presumed to reduce methane emissions by 48% compared with continuous flooding of rice fields (UN FAO 2010). However, some have suggested that by the nature of AWD creating nearly saturated soil conditions, it may promote N<sub>2</sub>O production. Wassmann et al. (2009) conclude that there are conflicting reports on the net global warming potential (GWP) of AWD, but there seems to be a growing consensus that this practice decreases the net GWP of paddy fields as long as nitrogen is applied in appropriate doses and, as commonly practiced in the Mid South, when large amounts of rice straw are returned to the soil. Bouman et al. 2007 concludes AWD generates multiple benefits related to reducing water use, reducing methane emissions (mitigation), increasing productivity, and increasing food security.

## **Data and Methods**

### *Site Description*

In 2011 and 2012 a water management study was carried out at the University of Arkansas’ Rice Research and Extension Center near Stuttgart, Arkansas (N 34°27' lat; W 091°24' long) on a Dewitt silt loam (fine, smectitic, thermic, Typic Albaqualfs; USDA, 2006). The study site was previously managed as a rice-soybean rotation. In both years, the rice crop being studied was planted following soybean. The field was managed so that each year’s planting was adjacent to that of the previous year. Composite soil samples were collected to a 15-cm depth from each replication area in March 2012.

### *Methane Treatments and Experimental Design*

In both years the study contained four replications and the following six water treatments: 1) flood, 2) AWD/40-flood, 3) AWD/60, 4) AWD/40, Row Rice (RW)/60, and RW/40 where AWD represents alternate wetting and drying followed by the percent of saturated soil water holding capacity at which fields were re-flooded to a depth of 10-cm. For the AWD/40-flood treatment the AWD/40 management was maintained from initial flood to the plants reaching the R0-R1 growth stage (Counce et al. 2000); after which a 10-cm flood was maintained until the field was drained. Row water treatments consisted of rice planted across beds that were 10-cm in height and 75-cm across. Water treatments (main plots 8.5 x 30.5-m) were randomly split to accommodate two 4.24 x 30.5-m variety sub-plots. In 2011 CLXL745 and XL723 (RiceTec) hybrid varieties were grown. In 2012 CLXL745 and XL753 were used. All rice plantings were dry seeded into 19-cm rows using an Almaco no-tillage grain drill (Almaco, Nevada, IA) at a seeding rate of 30 kg seed ha<sup>-1</sup>. All plots received an application of Command (clomazone) at a rate of 0.56 kg ha<sup>-1</sup> and Facet (quinclorac) at a rate of 0.34 kg ha<sup>-1</sup> immediately following planting. When the plants reached the V4-V5 growth stage, and prior to flooding the field, Clincher (cyhalofop) at 0.31 kg ha<sup>-1</sup>, Permit (halosulfuron) at 0.053 kg ha<sup>-1</sup>, and Facet (quinclorac) at 0.22 kg ha<sup>-1</sup> were applied and the field flooded.

All plots received a single phosphorus and potassium application of 29 kg P ha<sup>-1</sup> and 84 kg K ha<sup>-1</sup> as triple-super phosphate and muriate of potash, respectively, prior to tilling the field in the early spring. A single nitrogen application in the form of urea at 144 kg N ha<sup>-1</sup> was made just prior to the plots receiving their initial water treatment application. For the flood and AWD water treatments, the initial flood was maintained for 10 days after which the AWD treatments were allowed to dry via evapotranspiration. For the RW treatments, water was applied slowly during

the first water application to minimize fertilizer movement down the field. When a water treatment in a majority of replications reached the R7 growth stage, no further water was applied and those plots containing water were drained. A 3.0 x 30.5-m area of each plot was harvested to determine grain yield and samples for further analysis.

### *Sample Collection and Analysis*

Prior to spring tillage (March) composite of ten soil samples were collected in each replication to a 15-cm depth using a 10-cm diameter, stainless steel core chamber. Following collection, samples were manually broken up into pieces that were small enough to pass through a 6-mm sieve and air-dried for seven days at an approximate temperature of 22 °C. Sub-samples of air-dried soil were then ground for 12 hrs using a roller mill. In 2012 soil samples were collected following harvest from each main plot treatment and processed as previously described. Samples were analyzed using a Mehlich-3 procedure for extractable P, K, Ca, Mg, Na, S, Fe, Mn, Zn, and Cu (Mehlich, 1984). Total soil C and N were determined by high-temperature combustion using a LECO CN-2000 (LECO Corporation, St. Joseph, MI; Nelson and Sommers, 1996). Soil pH and electrical conductivity (EC) determinations were made using a 1:2 soil water mixture and measured by electrode. Soil organic matter was determined by loss-on-ignition (Schulte and Hopkins, 1996). At the time of harvest, 4-kg sub-samples were collected from each treatment as the grain was augured from the combine collection bin. These samples were dried at 45° C to a 12% moisture content and placed in seed storage.

### *Non-Methane GHG Emissions*

Multiple GHG's associated with global warming, were converted to their CO<sub>2</sub> equivalent to obtain a "carbon footprint" for all inputs used in rice production. Values provided by the US

Environmental Protection Agency (EPA) were used for diesel. EcoInvent's life cycle inventory database through SimaPro (2009) was used to calculate the upstream emissions from the production of fuel. Typically 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<sub>2</sub>) 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.

McFadden et al. (2013) conducted a variety specific life cycle analysis and found large differences between GHG emissions between hybrids and conventional varieties but not across hybrid varieties. This is not surprising given the fact that all "modern hybrids" have the same input (fertilizer, herbicide, fungicide, flood depth, etc.) recommendations so on a per acre basis the carbon footprint across hybrids, like the ones analyzed in this study, should be equivalent.<sup>1</sup> Thus, this study will assume all inputs and associated GHG's are equivalent between each of the three hybrid varieties (CLXL745, XL753 and XL72). The only differences between GHG emissions will be between irrigation regimes resulting in differences between (1) methane emissions and (2) emissions from running irrigation equipment. That is, because AWD uses less water than traditional flooding there will be a measured difference in the amount of diesel needed to raise that water. The study assumed that water for irrigation was pumped from 74.11 feet using a diesel pump which required 1.022 gallons of diesel to raise one acre-inch of water

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<sup>1</sup> The only difference being that the Clearfield® hybrids use a different type of herbicide, Newpath, but at similar rates of application. Thus the only difference in GHG emissions per acre would be associated with the emissions associated with the active ingredients between herbicides.

(Slaton 2001).<sup>2</sup> The average depth of the Alluvial Aquifer, on the Arkansas side is estimated to be 74.11 so this was chosen to represent the average pumping cost for irrigation (ANRC, 2012). So, GHG reductions in this study are a result of switching from traditional flooding to an AWD irrigation régime resulting in less methane emissions from a reduced flood and reduced CO<sub>2</sub> emissions from reduced diesel required for irrigation.<sup>3</sup> As such, CO<sub>2</sub> mitigation payments could be paid to a producer for switching to AWD from traditional flooding.

### *Carbon Payments*

A mitigation price of \$5.91 per ton of CO<sub>2</sub>e was used as it was the 2013 futures price on the European Carbon Futures market on the European Energy Exchange (EEX). Thus as an example, reducing irrigation by 15 acre/inches would result in a carbon payment of \$1.14 per acre. Where each gallon of diesel fuel is equivalent to 25.81 lbs/CO<sub>2</sub>e (EPA, 2013) multiplied by 15 ac/in (387.2) divided by 2,000 from tons to pounds (0.1936) times \$5.91(carbon price) results in a mitigation payment of \$1.14. While carbon payments for diesel are relatively small those for methane can be relatively much larger (given methane emissions for flooded rice often exceed a ton per acre) giving a producer a potential incentive to switch to AWD. It should be noted that the authors are not suggesting that these carbon mitigation payments are large enough to trigger switching to AWD but view this payments as partially offsetting the yield loss that typically comes with AWD.

### *Social Cost of Water*

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<sup>2</sup> Assuming a 75 percent pump efficiency and 5 percent drive loss.

<sup>3</sup> Roughly 50% of irrigation wells in Arkansas are powered by electric motors. That being said, the amount of CO<sub>2</sub> released to raise an acre inch of water is higher when using an electric motor given the source of the electricity production. Thus, the estimates from this study should be slightly conservative.

Pumped groundwater, in addition to increasing the water supply, mitigates undesirable fluctuations in the water supply. Here we describe how to assign an economic value to this stabilization role (Tsur, 1990). Let the uncertain supply of surface water,  $s$ , be distributed according to a cumulative distribution having a moment vector  $\theta$  with the mean  $\mu$  and the variance  $\sigma^2$ .<sup>4</sup> In the absence of groundwater, growers use the surface water available and enjoy the operating profit per acre of  $pF()$ , where  $F()$  represents per acre yield response to water, and  $p$  is the net unit value of the crop. The demand for groundwater by growers is determined after the observed precipitation occurs. This ex post situation is most realistic and is what prevails in the Arkansas region.

The stabilization (or buffer) value of groundwater for irrigation is defined as

$$BV(p, \theta) = B_u(p, \theta) - B_c(p, \mu).$$

The buffer value  $BV$  equals the difference between the benefits of groundwater in the uncertain and the certain environments.  $BV$  is the amount a grower facing an uncertain surface water supply would be willing to pay for groundwater over the corresponding amount that is willing to be paid if the surface water supplies are certain at  $\mu$ . This is a measure of how much a producer would be willing to pay to move from a situation in which surface water supplies fluctuate symmetrically about a mean  $\mu$  to a stable environment in which this supply is fixed at the level  $\mu$ .

Tsur (1990) shows that  $BV(p, \theta) = pF(\mu) - pE\{F(s)\}$ . The availability of groundwater shifts uncertainty from production to costs. The linearity in costs for groundwater implies producers are indifferent to uncertainty in costs, but production is concave in the water input

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<sup>4</sup> In the Arkansas region, surface water derives largely from precipitation and is independent of groundwater source.

meaning stability in the water input is valuable. Using Jensen's inequality,  $BV$  is approximated by  $BV \cong 0.5p[-F''(\mu)]\sigma^2$ . This indicates the  $BV$  depends on the value of marginal productivity of water at input level  $\mu$ , the degree of concavity of  $F$  at  $\mu$ , and the variance of surface water supply  $\sigma^2$ .

### *Social Cost of Water Data*

Monthly rainfall data are collected from the Wynne, Arkansas weather station from June to September when groundwater is typically applied to rice in the Delta over thirteen years from 2000 to 2012 (NOAA, 2013). For the four month season over the thirteen years, the average seasonal rainfall is 12 inches and the variance of the seasonal rainfall is 19 inches squared. Data on rice yield for varying levels of water input come from field observations of alternate wet-dry and flood irrigation. Several functional forms are estimated for the response of rice yield to water input, and the natural log form is chosen based on fit to determine the concavity of rice yield response to water input at the average rainfall for the season,  $[-F''(\mu)]$ , estimated to be 0.1753. The net unit value of rice is the price of a hundred-weight of rice from the five year average of December futures prices for harvest time contracts (GPTC, 2012) at \$6.327 per bushel less the costs of production for a hundred-weight of rice based on production budgets (Division of Agriculture, 2012) of \$3.279 per bushel, making the net unit value of rice equal to \$3.047. The buffer value for eleven acre-inches of groundwater which is the difference of the water applied for conventionally grown and AWD rice is:

$$BV \cong 0.5p[-F''(\mu)]\sigma^2 = 0.5*3.047*0.1753*19.4 = \$5.189.$$



The estimate for the buffer value (or social cost of water) per acre-inch for the rice is then:  
\$5.189/11 acre-inches is \$0.47 per acre-inch.

## **Results**

All model variations; (1) AWD vs traditional flooding; (2) AWD with carbon payments vs traditional flooding; (3) AWD with social cost of water payments vs traditional flooding; and (4) AWD with carbon payments and social cost of water payments vs. traditional flooding were analyzed under varying diesel and rice prices ranging from \$3.20 - \$4.40 per gallon and \$2.50 - \$7.00 per bushel, respectively. Excluding water availability, these two costs are the largest when contemplating adopting AWD irrigation. Rice price plays a large role given the fact that AWD is often associated with lower rice yield and thus lower revenue which can be analyzed as an opportunity cost. Table 1 indicates that on average across all years if a producer grows CLXL745 their yields would decrease by 11.54 bu/ac if they switched from traditional to AWD/40 irrigation. Given today's rice price of \$6.21 per bushel, that would result in a loss of \$71.66 per acre. Across the three AWD scenarios CLXL745 has the lowest average yield loss at 5.26% followed by XL723 and XL753 with 7.16% and 8.65%, respectively. Thus, there would be a disincentive to adopt AWD flooding unless there was a countervailing incentive, which is the reduction in diesel usage. An advantage of AWD is lower fuel usage, as diesel price increases so does the attractiveness of AWD in terms of savings associated with pumping costs. Table 1 illustrates that switching from traditional flooding to AWD/40 a producer could reduce diesel usage by 10.80 gallons per acre. Given off-road diesel price today of \$3.17 per gallon a producer would save \$34.24 on diesel costs by switching to AWD/40 from traditional flooding. That being said, from our example above we indicate that switching from traditional flooding to AWD would on average cost a producer \$71.66 per acre resulting in a net loss of \$37.42 per acre.

Therefore, unless there were additional incentives to adopt AWD it does not look economically feasible in Arkansas.

Table 3 illustrates the efficiency measures in terms of GHG emissions and water usage per bushel of rice produced by variety and flooding régime. The average amount of water used to produce a bushel of rice under traditional flooding was estimated to be 3,911 gallons which is 1.56 times the amount to grow an average bushel of corn ( USDA-ARS, 2011). Switching from traditional flooding to AWD/40 on average was found to save 321 gallons per bushel (8.2% efficiency gain), AWD/40 flood was found to save 546 gallons per bushel (13.9% efficiency gain) and AWD/60 was estimated to save 1,170 gallons per bushel (a 30% efficiency gain). This seems counter intuitive given that AWD/60 uses substantially more water than AWD/40 but the yield losses associated with AWD/60 are 4.25% less than with AWD/40; thus the efficiency ratio of yield to water used is higher. Table 3 also highlights the increased efficiency rice bushels per unit of GHG (methane in this case) emitted. Traditional flooding was estimated to on average (across all varieties) emit ten pounds of methane for every bushel of rice produced. AWD/40 reduced that ratio to 0.21 lbs of GHG per bushel (a 98% increase in efficiency), AWD/40-Flood had a ratio of 5.4 lbs of GHG per bushel (a 46% increase in efficiency) and AWD/60 was estimate to have an average ratio of 0.4 lbs of GHG per bushel of rice (a 96% increase in efficiency). Thus, from an environmental efficiency standpoint all forms of AWD irrigation are superior to traditional flooding. That being said, often times there is a divergence between environmental efficiency and profit maximization. Government recognizing that the values of a stable climate or an abundant aquifer are often not internalized in the private marketplace may establish regulations that generate payments or taxes for use of these resources. The remaining

results section explores the economic viability of AWD when there are incentives (carbon payments and water savings payments) for the adoption of AWD.

#### *AWD vs Traditional Flooding*

Table 4 illustrates that under straight up head to head comparisons that AWD/40 is only more profitable with rice prices that are near historic lows and high diesel prices. This is attributable to the fact that on average AWD/40 yields 10.77% less (Table 2) than traditional flooding and thus to make it more attractive rice price would need to be low as to allow diesel costs savings to mitigate revenue losses. AWD/60 fairs the best amongst the three AWD alternatives but still is not competitive given today's diesel and rice prices. The average yield loss from AWD/60 is larger than AWD/40-Flood (6.53 vs. 3.76) but given low amount of water applied to AWD/60 it becomes more attractive economically as diesel savings outweighs yield reductions, in a relative sense. Using the matrix provided on Table 4 and current diesel (\$3.17 per gallon) and rice price (\$6.21 per bushel) these results would indicate that producers who switched from traditional flooding to AWD/40 would stand to lose roughly \$72 per acre, \$26 per acre by switching to AWD/40-Flood and \$37.32 per acre by switching to AWD/60. To put these losses in perspective the 2014 University of Arkansas Cooperative Extension Crop budgets estimate that hybrid rice profits per acre to be \$357.50 indicating that adopting AWD/40 would result in a 20.1%, 7.3% and 10.4% loss respectively in profits per acre. These results indicate that from a head to head standpoint under current prices there is no incentive for producers to switch to any AWD irrigation method from a short term economic standpoint.

#### *AWD with carbon payments vs traditional flooding*

Table 5 illustrates those iterations where AWD is more profitable than traditional flooding. The red shaded cells represent those price (diesel and rice) iterations that were not profitable without a carbon mitigation payment but are profitable now with one included in total revenue function. Intuitively, one would assume that AWD/40 would be the largest benefactor of carbon payments (in the form of methane reductions) but as illustrated on Table 4 AWD/40-Flood still looks to be the most attractive alternative. This is primarily due to the fact yield loss associated with AWD/40-Flood is less than that of AWD/40, 3.76% and 10.77%, respectively. While the carbon offset payment makes all of the AWD irrigation methods more attractive they still appear to be economically unfeasible. Given current diesel (\$3.17 per gallon) and rice price (\$6.21 per bushel) these results would indicate that producers who switched from traditional flooding to AWD/40 would stand to lose roughly \$61 per acre, \$20 per acre by switching to AWD/40-Flood and \$25 per acre by switching to AWD/60. Again, given the expected hybrid profits per acre put forth by University of Arkansas Cooperative Extension 2014 Crop budgets of \$357.50 would indicate that adopting AWD/40 would result in a 17.1%, 5.6% and 7.0% loss respectively in profits per acre. Again, it would appear that AWD/40-Flood appears to be the most economically feasible option followed by AWD/60 and AWD/40, respectively. It should be worth noting that given the fact some rice purchasing companies (Kelloggs and Mars) are seeking out “sustainable rice” they may be willing to incur these losses and pay the producer the difference to entice the producer to adopt the more sustainable AWD production methods.

*AWD with payments for the social cost of water vs traditional flooding*

Table 6 illustrates those iterations where AWD is more profitable than traditional flooding. The green shaded cells represent those price (diesel and rice) iterations that were not profitable without a social cost of water payment but are profitable now with one included in

total revenue function. Here the largest relative winner is AWD/40 because of its large water use reduction from traditional flooding, a reduction of 55%. However; large water savings payment cannot overcome the large yield reduction associated with AWD/40 and thus it still is the least attractive of the three alternative irrigation methods in terms of profitability. Given current diesel (\$3.17 per gallon) and rice price (\$6.21 per bushel) these results would indicate that producers who switched from traditional flooding to AWD/40 would stand to lose roughly \$63 per acre, \$21 per acre by switching to AWD/40-Flood and \$27 per acre by switching to AWD/60. These results nearly mirror the results of producers receiving a carbon payment both in relative magnitude and absolute decrease. Again, it appears that payments made to producers for adopting AWD irrigation methods equivalent to the social cost of water alone is not enough of an economic incentive to entice a switch. Given expected profits from the 2014 \$357.50 indicating that adopting AWD/40 would result in a 17.1%, 5.6% and 7.0% loss respectively in profits per acre.

*AWD with payments for the social cost of water and carbon payments vs traditional flooding*

Table 7 illustrates those iterations where AWD is more profitable than traditional flooding. The blue shaded cells represent those price (diesel and rice) iterations that were not profitable without a social cost of water and carbon payments but are profitable now with one included in total revenue function. Again, you can see the vertical vs horizontal tradeoff on Table 6 with AWD/60 faring better than AWD/40 with higher rice prices (due to less of a yield loss) and higher diesel prices (due to the reduction in pumping costs) . Given current diesel (\$3.17 per gallon) and rice price (6.21 per bushel) these results would indicate that producers who switched from traditional flooding to AWD/40 would stand to lose roughly \$56 per acre,

\$18 per acre by switching to AWD/40-Flood and \$20 per acre by switching to AWD/60. Given the expected hybrid profits per acre put forth by University of Arkansas Cooperative Extension 2014 Crop budgets of \$357.50 adopting AWD/40 would result in a 15.7%, 5.0% and 5.6% loss respectively in profits per acre. Again, even with the carbon and social cost of water payments given to producers AWD looks to associated with a minimum of a 5% profit loss for producers. That being said, this appears to be well within a margin which a company such as MARS or Kellogg's could pay to source "sustainable rice".

These results should also be considered static with the price of carbon which is unrealistic. Carbon markets are currently thinly traded and thus few places to purchase offsets and thus the sticky European carbon price of \$5.91 per ton. That being said, the EPA predicted a US carbon price between \$10 and \$30 per ton if the Waxman-Markey Bill would have passed in 2011 (US EPA, 2011). To put this in perspective, AWD/60 would be more profitable than traditional flooding with a CO<sub>2</sub>e/ton price \$27. Other caveats about this study are the pumping depth used of 74.11 feet will only increase as the Alluvial aquifer falls. In many places in the aquifer 100+ feet wells are not uncommon and thus AWD would look more attractive

## **Conclusions**

Rice production in the United States is beginning to experience constraints on aquifer depletion and increased demand from private industry to reduce GHG emissions associated with rice production. This study investigates the potential economic viability of alternate wet dry (AWD) irrigation in the Mid-South. AWD is an irrigation régime where the producer allows the rice field to dry intermittently during the rice life-cycle rather than having the field continuously submerged. In previous studies AWD has been found to reduce water usage by from 20-70% and

to reduce methane emissions by almost 50% as compared to rice produced under continuous flooding. However; the large disadvantage of AWD is that it is often times associated with yield.

The results of the four scenarios (1) AWD vs traditional flooding; (2) AWD with carbon payments vs traditional flooding; (3) AWD with social cost of water payments vs traditional flooding; and (4) AWD with carbon payments and social cost of water payments vs. traditional flooding offer conclusions relevant to rice industry and producer interests. Relative to traditional flooding switching to AWD lowers producer profits from 7-20% based on which AWD régime is chosen. Environmentally and economically beneficial outcomes are thus not profitable without further economic incentives such as a carbon or water conservation payment. With the introduction of carbon abatement payments for reducing methane and CO<sub>2</sub> emissions producers who adopt AWD would still stand to lose between 6-17% in profits compared to traditional flooding. Nearly identical results are found when payments are made for water conservation. That being said, when carbon abatement payments are made along with water conservation payments (equivalent to a water usage tax for traditional flooding) profits decrease between only 5-15%. From a societal standpoint switching to AWD can reduce CO<sub>2</sub>e by over one ton per acre which given that Arkansas alone has roughly one million acres of rice could play a major factor in lowering agricultures global warming potential.

This study's relevance depends on how rice consumers and buyers, like Kellogg's and MARS, incentivize "sustainable" rice production to producers. As it stands now, water availability notwithstanding, there is no economic incentive based on this study's results to convert to AWD. That being said, given the large "green" push from consumers large companies could incentive producers to switch to AWD by covering the roughly 5-7% loss associated with AWD/60. In doing so producers should be indifferent between AWD and traditional flooding

and large rice buyers can market their product as reducing on farm GHG emissions by over 50% and water usage by roughly the same amount. This study also has relevance given the increased regulatory demand regarding water. In Arkansas where the price of an acre inch of water is equivalent to the cost of diesel fuel needed to raise it, AWD could become much more popular if water rights/taxes are assigned.

Implications of this study for future research stem primarily from the assumptions used in building economic model. The assumption of constant water depth across the Delta in the Alluvial aquifer precludes any discussion about the high variability of depths and the reality that the aquifer will only continue to be depleted making the economic and social cost of AWD more attractive. Experimental generation of more data on cultivar specific and other thresholds for AWD will allow future studies to incorporate GHG emissions uncertainty to stochastic analyses of carbon abatement.

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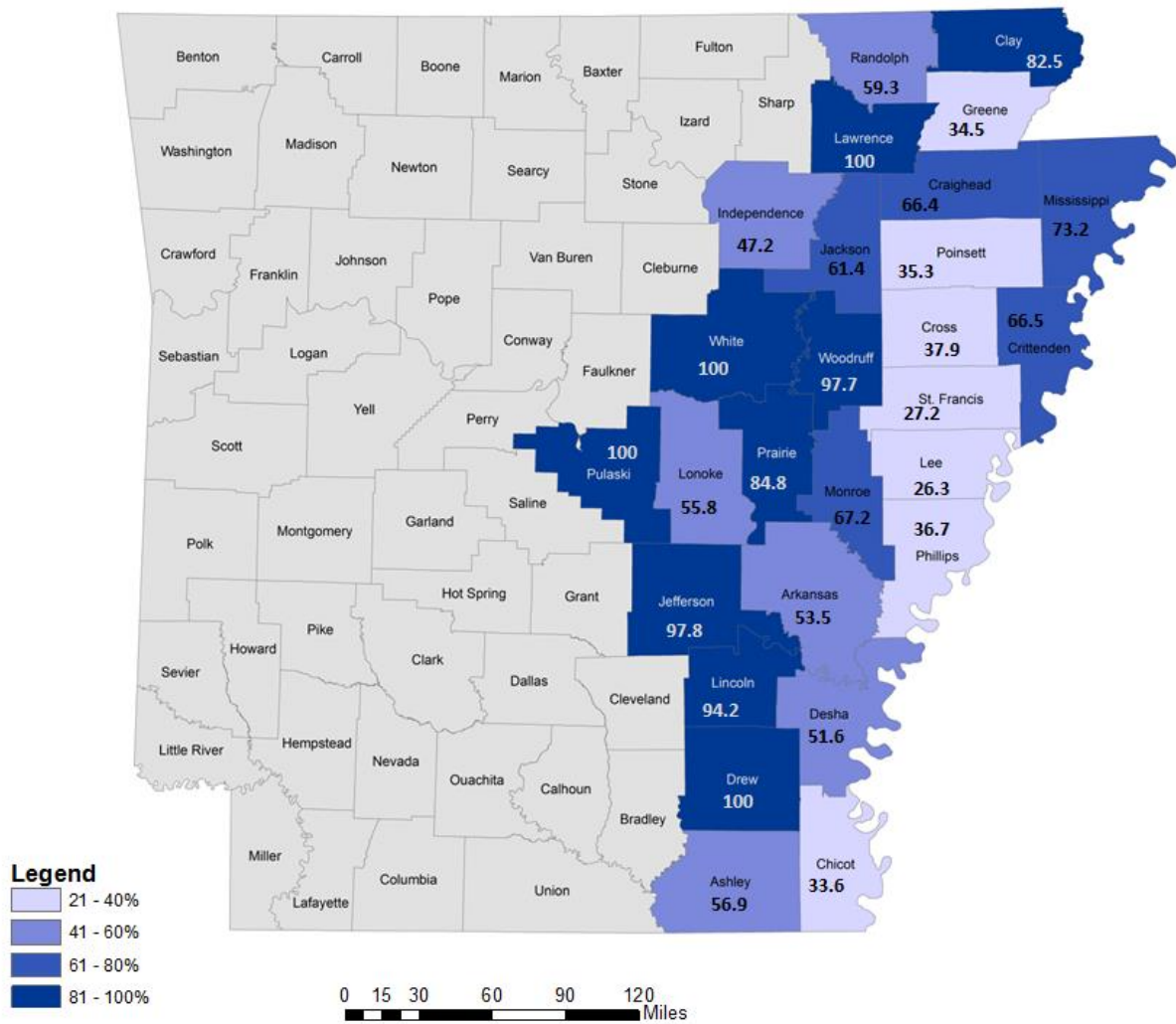
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Figure 1. County Level Percentage of 2009 Water Use Sustainable for the Alluvial Aquifer based on 1997 Pumping Rates.



Source: Arkansas Natural Resources Commission (2013)

Table1. Average Water Usage, Methane Emissions and Yield by Rice Variety Type and Irrigation Method: 2011-2013

Irrigation Treatment	Variety	Average Yield (bu/ac)	Average Water used (ac/in)	Average Methane (Tons of CO <sub>2</sub> e/acre)
<b>Flood</b>	CLXL745	204.46	30.40	1.06
	XL723	226.31	-	-
	XL753	203.92	-	-
<b>AWD/40</b>	CLXL745	192.74	19.60	0.02
	XL723	202.96	-	-
	XL753	177.76	-	-
<b>AWD/40- Flood</b>	CLXL745	195.39	25.20	0.55
	XL723	219.38	-	-
	XL753	197.05	-	-
<b>AWD/60</b>	CLXL745	194.64	20.00	0.04
	XL723	211.87	-	-
	XL753	189.27	-	-

Table 2. Average Percent Reduction in Yield, Water Usage, and Methane Emissions from Converting from Traditional Flooding to Various AWD Irrigation Régimes.

Irrigation Treatment	Variety	Average Yield Difference (bu/ac)	Average Water Usage Difference (ac/in)	Average Methane Difference (Tons of CO <sub>2</sub> e/acre)
<b>AWD/40</b>	CLXL745	-6.08%	-55.10%	-98.11%
	XL723	-11.50%	-	-
	XL753	-14.71%	-	-
	<b>Average</b>	<b>-10.77</b>		
<b>AWD/40- Flood</b>	CLXL745	-4.64%	-20.63%	-48.11%
	XL723	-3.16%	-	-
	XL753	-3.49%	-	-
	<b>Average</b>	<b>-3.76</b>		
<b>AWD/60</b>	CLXL745	-5.04%	-52.00%	-96.22%
	XL723	-6.81%	-	-
	XL753	-7.74%	-	-
	<b>Average</b>	<b>-6.53</b>		

Table 3 Water and GHG use Efficiency by Variety and Flooding Régime.

Irrigation Treatment	Variety*	Gallons of Water per Bushel of Rice**	Pounds of Methane (CO <sub>2</sub> e) Per Bushel of Rice***
<b>Flood</b>	CLXL745	4,037	10.37
	XL723	3,648	9.37
	XL753	4,048	10.40
	<b>Average</b>	<b>3,911</b>	<b>10.0</b>
<b>AWD/40</b>	CLXL745	3,550	0.21
	XL723	3,372	0.20
	XL753	3,849	0.23
	<b>Average</b>	<b>3,590</b>	<b>0.21</b>
<b>AWD/40- Flood</b>	CLXL745	3,502	5.63
	XL723	3,119	5.01
	XL753	3,473	5.58
	<b>Average</b>	<b>3,365</b>	<b>5.41</b>
<b>AWD/60</b>	CLXL745	2,790	0.41
	XL723	2,563	0.38
	XL753	2,869	0.42
	<b>Average</b>	<b>2,741</b>	<b>0.40</b>

\*Variety yields by irrigation régime are taken from Table 1.

\*\* Water usage amounts are taken from Table 1 and converted from acre inches to gallons.

\*\*\* Methane amounts are taken from Table 1 and converted from tons to pounds.

Table 4. Average Profit Difference per Acre for AWD vs. Conventional Flooding across all Rice Varieties in the Arkansas Delta under varying Rice and Diesel Prices.

<b>AWD/40</b>										
Rice Price (\$/bu)	\$2.50	\$3.00	\$3.50	\$4.00	\$4.50	\$5.00	\$5.50	\$6.00	\$6.50	\$7.00
Diesel Price (\$/gallon)										
\$3.20	-8.68	-17.81	-26.95	-36.08	-45.21	-54.34	-63.48	-72.61	-81.74	-90.87
\$3.50	-5.22	-14.35	-23.48	-32.61	-41.74	-50.88	-60.01	-69.14	-78.27	-87.41
\$3.70	-2.90	-12.04	-21.17	-30.30	-39.43	-48.57	-57.70	-66.83	-75.96	-85.09
\$3.90	-0.59	-9.73	-18.86	-27.99	-37.12	-46.25	-55.39	-64.52	-73.65	-82.78
\$4.10	1.72*	-7.41	-16.55	-25.68	-34.81	-43.94	-53.08	-62.21	-71.34	-80.47
\$4.20	2.87	-6.26	-15.39	-24.52	-33.66	-42.79	-51.92	-61.05	-70.18	-79.32
\$4.40	5.18	-3.95	-13.08	-22.21	-31.34	-40.48	-49.61	-58.74	-67.87	-77.01

<b>AWD/40-Flood</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	-0.55	-4.22	-7.98	-11.56	-15.23	-18.90	-22.57	-26.24	-29.91	-33.58
\$3.50	1.12	-2.55	-6.22	-9.89	-13.56	-17.23	-20.90	-24.57	-28.24	-31.13
\$3.70	2.24	-1.43	-5.10	-8.77	-12.44	-16.11	-19.78	-23.46	-27.13	-30.08
\$3.90	3.35	-0.32	-3.99	-7.66	-11.33	-15.00	-18.67	-22.34	-26.01	-29.68
\$4.10	4.46	0.79	-2.88	-6.55	-10.22	-13.89	-17.56	-21.23	-24.90	-28.57
\$4.20	5.02	1.35	-2.32	-5.99	-9.66	-13.33	-17.00	-20.67	-24.34	-28.01
\$4.40	6.13	2.46	-1.21	-4.68	-8.55	-12.22	-15.89	-19.56	-23.23	-26.90

<b>AWD/60</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	5.22	-0.82	-6.93	-13.01	-19.09	-25.16	-31.24	-37.32	-43.40	-49.47
\$3.50	8.56	2.48	-3.59	-9.67	-15.75	-21.83	-27.90	-33.98	-40.06	-46.13
\$3.70	10.79	4.71	-1.37	-7.45	-13.52	-19.60	-25.68	-31.75	-37.83	-43.91
\$3.90	13.01	6.94	0.86	-5.22	-11.30	-17.37	-23.45	-29.53	-35.61	-41.68
\$4.10	15.54	9.16	3.08	-2.99	-9.07	-15.15	-21.23	-27.3	-33.38	-39.46
\$4.20	16.35	10.27	4.20	-1.88	-7.96	-14.04	-20.11	-26.19	-32.27	-38.35
\$4.40	18.58	12.50	6.42	0.34	-5.73	-11.81	-17.89	-23.96	-30.04	-36.12

Note: Cell Values indicate the difference between AWD profits and traditional flooding profits

\* Shaded cells denote those price (diesel and rice) combinations which AWD irrigation was more profitable than traditional flooding.

Table 5. Average Profit Difference per Acre for AWD vs. Conventional Flooding across all Rice Varieties with Carbon Payments in the Arkansas Delta under varying Rice and Diesel Prices.

<b>AWD/40</b>										
Rice Price (\$/bu)	\$2.50	\$3.00	\$3.50	\$4.00	\$4.50	\$5.00	\$5.50	\$6.00	\$6.50	\$7.00
Diesel Price (\$/gallon)										
\$3.20	-8.68	-17.81	-26.95	-36.08	-45.21	-54.34	-63.48	-72.61	-81.74	-90.87
\$3.50	-5.22*	-14.35	-23.48	-32.61	-41.74	-50.88	-60.01	-69.14	-78.27	-87.41
\$3.70	-2.90	-12.04	-21.17	-30.30	-39.43	-48.57	-57.70	-66.83	-75.96	-85.09
\$3.90	-0.59	-9.73	-18.86	-27.99	-37.12	-46.25	-55.39	-64.52	-73.65	-82.78
\$4.10	1.72**	-7.41	-16.55	-25.68	-34.81	-43.94	-53.08	-62.21	-71.34	-80.47
\$4.20	2.87	-6.26	-15.39	-24.52	-33.66	-42.79	-51.92	-61.05	-70.18	-79.32
\$4.40	5.18	-3.95	-13.08	-22.21	-31.34	-40.48	-49.61	-58.74	-67.87	-77.01

<b>AWD/40-Flood</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	-0.55	-4.22	-7.98	-11.56	-15.23	-18.90	-22.57	-26.24	-29.91	-33.58
\$3.50	1.12	-2.55	-6.22	-9.89	-13.56	-17.23	-20.90	-24.57	-28.24	-31.13
\$3.70	2.24	-1.43	-5.10	-8.77	-12.44	-16.11	-19.78	-23.46	-27.13	-30.08
\$3.90	3.35	-0.32	-3.99	-7.66	-11.33	-15.00	-18.67	-22.34	-26.01	-29.68
\$4.10	4.46	0.79	-2.88	-6.55	-10.22	-13.89	-17.56	-21.23	-24.90	-28.57
\$4.20	5.02	1.35	-2.32	-5.99	-9.66	-13.33	-17.00	-20.67	-24.34	-28.01
\$4.40	6.13	2.46	-1.21	-4.68	-8.55	-12.22	-15.89	-19.56	-23.23	-26.90

<b>AWD/60</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	5.22	-0.82	-6.93	-13.01	-19.09	-25.16	-31.24	-37.32	-43.40	-49.47
\$3.50	8.56	2.48	-3.59	-9.67	-15.75	-21.83	-27.90	-33.98	-40.06	-46.13
\$3.70	10.79	4.71	-1.37	-7.45	-13.52	-19.60	-25.68	-31.75	-37.83	-43.91
\$3.90	13.01	6.94	0.86	-5.22	-11.30	-17.37	-23.45	-29.53	-35.61	-41.68
\$4.10	15.54	9.16	3.08	-2.99	-9.07	-15.15	-21.23	-27.3	-33.38	-39.46
\$4.20	16.35	10.27	4.20	-1.88	-7.96	-14.04	-20.11	-26.19	-32.27	-38.35
\$4.40	18.58	12.50	6.42	0.34	-5.73	-11.81	-17.89	-23.96	-30.04	-36.12

Note: Cell Values indicate the difference between AWD profits and traditional flooding profits

\*Carbon payment is based on the amount of CO<sub>2</sub>e mitigated by switching from traditional flooding to alternative AWD methods. The price used for a ton of CO<sub>2</sub>e is \$5.90.

\*Red shaded cells denote those prices (diesel and rice) combinations which were not profitable compared to traditional flooding without the introduction of a carbon payment but now are profitable.

\*\* Yellow shaded cells denote those price (diesel and rice) combinations which AWD irrigation was more profitable than traditional flooding.



Table 6. Average Profit Difference per Acre for AWD vs. Conventional Flooding across all Rice Varieties with Payments equivalent to the Social Cost of Water in the Arkansas Delta under varying Rice and Diesel Prices.

AWD/40										
Rice Price (\$/bu)	\$2.50	\$3.00	\$3.50	\$4.00	\$4.50	\$5.00	\$5.50	\$6.00	\$6.50	\$7.00
Diesel Price (\$/gallon)										
\$3.20	-8.68*	-17.81	-26.95	-36.08	-45.21	-54.34	-63.48	-72.61	-81.74	-90.87
\$3.50	-5.22	-14.35	-23.48	-32.61	-41.74	-50.88	-60.01	-69.14	-78.27	-87.41
\$3.70	-2.90	-12.04	-21.17	-30.30	-39.43	-48.57	-57.70	-66.83	-75.96	-85.09
\$3.90	-0.59	-9.73	-18.86	-27.99	-37.12	-46.25	-55.39	-64.52	-73.65	-82.78
\$4.10	1.72**	-7.41	-16.55	-25.68	-34.81	-43.94	-53.08	-62.21	-71.34	-80.47
\$4.20	2.87	-6.26	-15.39	-24.52	-33.66	-42.79	-51.92	-61.05	-70.18	-79.32
\$4.40	5.18	-3.95	-13.08	-22.21	-31.34	-40.48	-49.61	-58.74	-67.87	-77.01

AWD/40-Flood										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	-0.55	-4.22	-7.98	-11.56	-15.23	-18.90	-22.57	-26.24	-29.91	-33.58
\$3.50	1.12	-2.55	-6.22	-9.89	-13.56	-17.23	-20.90	-24.57	-28.24	-31.13
\$3.70	2.24	-1.43	-5.10	-8.77	-12.44	-16.11	-19.78	-23.46	-27.13	-30.08
\$3.90	3.35	-0.32	-3.99	-7.66	-11.33	-15.00	-18.67	-22.34	-26.01	-29.68
\$4.10	4.46	0.79	-2.88	-6.55	-10.22	-13.89	-17.56	-21.23	-24.90	-28.57
\$4.20	5.02	1.35	-2.32	-5.99	-9.66	-13.33	-17.00	-20.67	-24.34	-28.01
\$4.40	6.13	2.46	-1.21	-4.68	-8.55	-12.22	-15.89	-19.56	-23.23	-26.90

AWD/60										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	5.22	-0.82	-6.93	-13.01	-19.09	-25.16	-31.24	-37.32	-43.40	-49.47
\$3.50	8.56	2.48	-3.59	-9.67	-15.75	-21.83	-27.90	-33.98	-40.06	-46.13
\$3.70	10.79	4.71	-1.37	-7.45	-13.52	-19.60	-25.68	-31.75	-37.83	-43.91
\$3.90	13.01	6.94	0.86	-5.22	-11.30	-17.37	-23.45	-29.53	-35.61	-41.68
\$4.10	15.54	9.16	3.08	-2.99	-9.07	-15.15	-21.23	-27.30	-33.38	-39.46
\$4.20	16.35	10.27	4.20	-1.88	-7.96	-14.04	-20.11	-26.19	-32.27	-38.35
\$4.40	18.58	12.50	6.42	0.34	-5.73	-11.81	-17.89	-23.96	-30.04	-36.12

Note: Cell Values indicate the difference between AWD profits and traditional flooding profits

\*Social Cost of water is based on the amount of water (ac/in) saved by switching from traditional flooding to alternative AWD methods. The social cost of water was calculated in formula XX and estimated to be \$0.472 per acre inch.

\*Green shaded cells denote those prices (diesel and rice) combinations which were not profitable compared to traditional flooding without the introduction of a social cost of water but now are profitable

\*\* Yellow shaded cells denote those price (diesel and rice) combinations which AWD irrigation was more profitable than traditional flooding.

Table 7. Average Profit Difference per Acre for AWD vs. Conventional Flooding across all Rice Varieties with Payments for CO2 reduction and the Social Cost of Water in the Arkansas Delta under varying Rice and Diesel Prices

<b>AWD/40</b>										
Rice Price (\$/bu)	\$2.50	\$3.00	\$3.50	\$4.00	\$4.50	\$5.00	\$5.50	\$6.00	\$6.50	\$7.00
Diesel Price (\$/gallon)										
\$3.20	-8.68	-17.81	-26.95	-36.08	-45.21	-54.34	-63.48	-72.61	-81.74	-90.87
\$3.50	-5.22	-14.35	-23.48	-32.61	-41.74	-50.88	-60.01	-69.14	-78.27	-87.41
\$3.70	-2.90	-12.04	-21.17	-30.30	-39.43	-48.57	-57.70	-66.83	-75.96	-85.09
\$3.90	-0.59	-9.73	-18.86	-27.99	-37.12	-46.25	-55.39	-64.52	-73.65	-82.78
\$4.10	1.72	-7.41	-16.55	-25.68	-34.81	-43.94	-53.08	-62.21	-71.34	-80.47
\$4.20	2.87	-6.26	-15.39	-24.52	-33.66	-42.79	-51.92	-61.05	-70.18	-79.32
\$4.40	5.18	-3.95	-13.08	-22.21	-31.34	-40.48	-49.61	-58.74	-67.87	-77.01

<b>AWD/40-Flood</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	-0.55	-4.22	-7.98	-11.56	-15.23	-18.90	-22.57	-26.24	-29.91	-33.58
\$3.50	1.12	-2.55	-6.22	-9.89	-13.56	-17.23	-20.90	-24.57	-28.24	-31.13
\$3.70	2.24	-1.43	-5.10	-8.77	-12.44	-16.11	-19.78	-23.46	-27.13	-30.08
\$3.90	3.35	-0.32	-3.99	-7.66	-11.33	-15.00	-18.67	-22.34	-26.01	-29.68
\$4.10	4.46	0.79	-2.88	-6.55	-10.22	-13.89	-17.56	-21.23	-24.90	-28.57
\$4.20	5.02	1.35	-2.32	-5.99	-9.66	-13.33	-17.00	-20.67	-24.34	-28.01
\$4.40	6.13	2.46	-1.21	-4.68	-8.55	-12.22	-15.89	-19.56	-23.23	-26.90

<b>AWD/60</b>										
Rice Price (\$/bu)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50
Diesel Price (\$/gallon)										
\$3.20	5.22	-0.82	-6.93	-13.01	-19.09	-25.16	-31.24	-37.32	-43.40	-49.47
\$3.50	8.56	2.48	-3.59	-9.67	-15.75	-21.83	-27.90	-33.98	-40.06	-46.13
\$3.70	10.79	4.71	-1.37	-7.45	-13.52	-19.60	-25.68	-31.75	-37.83	-43.91
\$3.90	13.01	6.94	0.86	-5.22	-11.30	-17.37	-23.45	-29.53	-35.61	-41.68
\$4.10	15.54	9.16	3.08	-2.99	-9.07	-15.15	-21.23	-27.3	-33.38	-39.46
\$4.20	16.35	10.27	4.20	-1.88	-7.96	-14.04	-20.11	-26.19	-32.27	-38.35
\$4.40	18.58	12.50	6.42	0.34	-5.73	-11.81	-17.89	-23.96	-30.04	-36.12

Note: Cell Values indicate the difference between AWD profits and traditional flooding profits

\*Social Cost of water is based on the amount of water (ac/in) saved by switching from traditional flooding to alternative AWD methods. The social cost of water was estimated to be \$0.472 per acre inch. Carbon payment is based on the amount of CO2e mitigated by switching from traditional flooding to alternative AWD methods. The price used for a ton of CO2e is \$5.90

\*Blue shaded cells denote those prices (diesel and rice) combinations which were not profitable compared to traditional flooding without the introduction of a social cost of water but now are profitable

\*\* Yellow shaded cells denote those price (diesel and rice) combinations which AWD irrigation was more profitable than traditional flooding.