Economics of Carbon Credits from Voluntary Practices on Rice Farms in the Sacramento Valley

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1. Project Background

According to the California Air Resources Board (2010), rice cultivation in California is the third largest agricultural source of methane emissions in the state, after enteric fermentation and manure management. [1] The relatively high emission profile of rice motivates research on the potential for rice growers to reduce their greenhouse gas emissions through the voluntary adoption of alternative cultivation practices.

This report includes the economic analysis to accompany results from applying a biophysical agronomic model of soil and other interactions to determine projected greenhouse gas (GHG) outcomes from a series of voluntary alternative cultural practices, irrigation and water management and straw management practices in California rice. The context for this research is the implementation of state regulations affecting GHG emissions that consider the agricultural industry a voluntary emissions sector and, therefore, offer agriculture the potential for markets that trade GHG emission credits or offsets to be available to California agriculture.

2. Objectives and Project Steps

This report provides an economic analysis of GHG emissions from alternative rice production practices in the Sacramento Valley. To this end, we have put together cost budgets for sets of cultural and post-harvest operations for rice growers that offer the potential for greenhouse gas mitigation.

Specifically, this project computes the production costs from implementing GHG emissions reduction practices using University of California Cooperative Extension crop budgets and other sources of information. In addition to the production cost analysis, we have assessed the possible financial return to producers from selling carbon offsets, and have evaluated the economic feasibility for producers from implementing GHG emissions reduction practices. It should be noted, however, that there is not yet an approved program or protocol for trading the offsets nor has there been a practice proven to be feasible considering all agronomic risks associated with implementation of candidate practices.

The first step of the analysis is to investigate the production costs faced by a typical grower and estimating changes in these costs from implementing GHG emissions reduction practices. We use University of California Cooperative Extension crop budgets and other sources of information to approximate costs associated with each practice considered by project colleagues.

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[1]While rice is third, it is important to note that emissions from rice are an order of magnitude lower than the others, with comparable emissions from enteric fermentation, manure management and rice being 8.70, 6.38 and 0.57 million tons of CH_4, respectively.

The next step includes an assessment of financial returns to producers from selling carbon offsets. We use net GHG emissions reduction estimates obtained by the project modelers to simulate the return to rice producers from carbon offsets under a range of carbon prices. We provide a hypothetical assessment of voluntary participation by California rice farmers in a cap-and-trade approach.

The final step includes an evaluation of rice supply responses to GHG emissions reduction practices by the California rice industry and potential markets for emission reductions. We develop a simple model to project effects on California rice production under each GHG emissions reduction practice if it were implemented on an industry-wide basis. To perform these simulations, we rely upon input-use and rice production results obtained from field experiments and estimates of market parameters (demand and supply elasticities and market shares) from recent literature and other relevant information. We also investigate acreage implications under alternative prices for GHG offset credits if they were to become available.

3. Rice in California

The majority of California rice is grown in the Sacramento Valley. Figure 1 shows the concentration of rice area in the basins of the Sacramento Valley. California specializes in the production of high quality japonica rice. Over 500,000 acres of land in the state are devoted to rice, and rice is one of the top ten agricultural exports for California. In 2009, the farm value of rice production in California was more than $500 million.

From 2008 through 2010, rice prices have been unusually high (more than $18 per hundredweight (cwt), with accompanying relatively high acreage and gross farm revenues. In the analysis below, we also consider some scenarios under what was the more normal price range of $8 per cwt plus a government payment of $1 per cwt tied directly to rice production.

4. Growing practices and GHG implications

This section discusses growing practices with emphasis on those practices that may have particular implications for GHG emissions and which feature in the scenarios discussed below.

Rice growers in the Sacramento Valley operate on a wide variety of soils and within different microclimates. They face different prices for water and land as well as different rental offers from waterfowl hunting clubs for the use of their winter-flooded fields. Despite the differences in conditions faced by producers, the economic feasibility of alternative practices can be assessed by simulating a representative grower. Alternative practices considered in this analysis include cultural operations such as drill seeding and mid-season drainage and post-harvest operations such as winter flooding, rice straw incorporation and rice straw baling. Each practice or combination of practices has different implications for greenhouse gas emissions. Modifying practices also necessitates changes in fertilizer, pest and water management that can influence GHG emissions.

4.1 Cultural Operations

The conventional cultural operations include fertilizer application and disease control, seed-bed

preparation, air broadcast seeding of the flooded fields (water seeded system), maintaining the rice field flood throughout the growing season, and draining a few weeks before harvesting. Below, we consider variations in the GHG implications of four alternative cultural practices and combinations among them.

4.1.1 Drill seeding

Drill seeding requires the field to be precisely leveled and a fine tilled seedbed to ensure good germination. The heavier the soil, the more tractor passes are needed to obtain a fine till (approximate cost of $15-20 per acre per tractor pass, Steve Butler, Personal communication). Drill seeding practiced on heavy soil requires careful soil preparation and good water management. The successful transition from a water seeded system to a drilled seeded system on heavy clay requires experience and additional skill sets (Randall Mutters, Personal communication).

Rice growers mentioned that drill seeding provides them with greater control over their operations, as they gain flexibility in scheduling on-the-ground operations instead of relying on custom services, e.g., for air broadcast seeding (Steve Butler and Randall Mutters, Personal communication).

Drill-seeding requires using a dry fertilizer starter, such as ammonium sulfate (21-0-0-24) at $0.158/lb, urea (46-0-0) at $0.253/lb, or 16-20-0 at $0.195/lb, which is more expensive than the usual aqua ammonia (20-0-0) at $0.088/lb (2009 prices from Ricketts 2010).

In California, weed resistance to herbicides is an important issue. Drill seeding permits the use of some herbicides to which rice field weeds have not yet developed resistance. Additionally, if done properly, drill seeding has the potential to reduce herbicide cost by as much as half. For example, in a conventional system growers typically apply $125-150/acre of water-weed herbicide, whereas one grower conducting drill seeding may control weeds for as little as $40/acre for herbicides (Randall Mutters, Personal communication).

4.1.2 Mid-season drainage

California rice is typically grown under continuous flooded conditions. The impacts of extended drainage periods proposed by this practice are unknown. The objective of this practice is to cut down methane (CH_4) emissions by breaking the anaerobic cycle. There is a large body of literature on field experiments in Asia documenting the mitigation of CH_4 emissions (Li et $al.$, 2002; Qui, 2009). However, the creation of aerobic conditions may increase nitrous oxide (N_2O) emissions (Li et $al.$, 2002; Qui, 2009). In 2009 a mid-season drainage pilot project was run in the Sacramento Valley to collect data on management cost, yield impacts, and other related agronomic factors relevant to determining the viability of this practice for California growers.

California conditions for rice differ from those in rice-growing regions in Asia. The rice fields in Asia are predominately small and growers transplant plants creating a uniform distribution and distinct rows across the field. These conditions allow rice paddies to drain well and be re-flooded quickly. California fields are large and air broadcast seeded making water movement in and out of the field more difficult, leading to potential water-stress to the plants.

Furthermore, mid-season drainage may not be well-suited to the Sacramento Valley climatic conditions, in particular temperature (Kottek et al, 2006). California rice is grown among the highest latitudes—between the 38° (latitude of the border between North and South Korea) and 40° latitudes (latitude of Beijing, China). The summer nights are cool, and days very hot, which may damage rice plants in drained fields where there is no water to buffer against temperature extremes.

4.2 Post harvest operations

Post-harvest operations include field burning, leaving the rice straw to decompose on the field—with different possible degrees of incorporation into the soil—and a small amount of rice straw baling. Furthermore, fields can be flooded in the fall, or simply rain fed (Mutters et al. 2004 and 2007).

4.2.1 Burning

During the 1990s, California rice growers curtailed the practice of burning rice straw by about 75 percent. Until 1991, field burning was the most common practice to deal with rice straw. However, visibility and air quality problems in the Sacramento Valley led to mandated reductions in the amount of acreage that rice growers could burn (Carey 1999, Bird et al. 2002 Wong 2003). The Connelly-Arias-Chandler Rice Straw Burning Reduction Act mandated that starting in 1992, the percentage of burned over planted acres be reduced by approximately ten percent annually over an eight-year period (Carey, 1999). After September 2001, burning was permitted only for disease control, and no more than 25 percent of total rice acreage in the state and 125,000 acres in the valley could be burned annually. In fact, due to local limits on when burning is allowed, only about 12 percent of rice fields were burned in 2009 – a percentage that is representative of recent years.

4.2.2 Baling

A practice that may potentially mitigate greenhouse gas (GHG) emissions is straw removal through baling. According to preliminary simulations conducted by William Salas, baling could reduce greenhouse gas (GHG) emissions in the Sacramento Valley by as much as 30 percent.

Revenues from rice straw baling mainly depend on the price for straw in a given year and input costs associated with baling (Ken Collins, Personal communication). Initiatives launched by state agencies and private enterprises have failed to realize large-scale commercial usage of rice straw and the market for rice straw has not grown as anticipated (Hrynchuk, 1998; Bird *et al.,* 2002; Wong, 2003). As of late 2000, about 75 percent of the straw was ploughed back into the soil to dispose of the straw, and less than 3 percent of the estimated harvestable 1.13 million tons of straw was used off-field (Bird *et al.,* 2002; Wong, 2003). The outlook for large-scale commercial uses was considered poor (Hrynchuk, 1998; Bird *et al.,* 2002; Wong, 2003). About 7 percent of acreage had straw removed from the field in 2010 (Buttner 2011). Obviously, baling would increase if a strong market developed for rice straw.

According to a 2006 UC Cooperative Extension publication, rice straw baling costs ranged from

$25 to $40 per ton. If rice straw is sliced and flail chopped before baling, then costs ranged from $30 to $49 per ton (Nader and Robinson 2006). An older study conducted by UC Davis in 1997 estimated baling costs at $33/acre for small bales, and $18-30 per acre for large bales (Bakker-Dhaliwal, 1999). These 15 year old estimates have not been adjusted for inflation. Based on conversations with growers and rice experts, AIC estimates baling to cost around $45-55 per acre in an average year (Don Bransford, Glenn Nader, Chris Greer, Pete Livingston and Randall Mutters, Personal communications). Buttner (2011) suggests costs for baling in the range of $60 to $65 per acres for 2010.

Depending on the previous rice straw management practices, baling may imply nutrient losses, including nitrogen and potassium. Potassium is the most affected nutrient (Bird *et al.,* 2002). For the red soils of the east side of the valley, potassium will likely become yield limiting and potash supplements are required if growers decide to bale (Randall Mutters, Personal communication). A potash fertilizer at the maintenance rate of 50lbs/acre may be necessary (Mutters *et al.,* 2007) at a cost of about $25/acre (Ricketts 2009).

4.2.3 Winter flooding

During the winter, growers can flood their fields or rely on rainfall to submerge their fields. In the 1999-2000 crop year, 39 percent of rice fields in the Sacramento Valley were flooded during the winter, as outlined in Table 1. However, according to Randall Mutters, about 60 percent of fields are now flooded during the winter, and we base our calculations on this assertion. Farmers' decision to flood their fields during the winter depends on the price of water (typically cheaper in the north than in the south of the valley), the suitability of the location for ducks and geese (usually better habitats in the east side of the valley), and the probability of rainfall (relatively homogeneous spatially but very variable across years). Winter flooding contributes to straw decomposition (Fleshes *et al.,* 2005), and growers may be able to derive revenue from leasing winter-flooded fields for duck hunting (Virginia Getz, Ducks Unlimited, Personal communication).

Winter flooding increases methane production (Bird *et al.,* 2005). However, it is also associated with environmental benefits. The phase-down of straw burning and the increase in rice straw incorporation combined with winter flooding has substantially increased the provision of foraging habitat for migratory waterfowl. Fleshes *et al.* (2005) report waterfowl density as high as 33 birds per hectare per season on flooded rice fields. The Central Valley of California provides habitat for 60% of wintering waterfowl migrating along the Pacific Flyway (between 2 and 4 million birds).

4.2.4 Rice straw incorporation

In the Sacramento Valley common practices for incorporating rice straw include chopping, discing, flooding, and rolling. Most growers use a combination of discing and flooding (Mutters et al., 2004 and 2007).

To account for the variety of conditions faced by growers and the straw incorporation practices they could adopt, we conducted interviews with rice experts and growers from different sides of

the Sacramento Valley. We found that both in the north and south, the representative grower chops, discs, and floods. Because of the heavy soil, he conducts two cutting operations (chopping and discing) to get better straw decomposition. If it rains after the harvest and the field becomes wet, these operations cannot be conducted and he floods and stumps. Other problems occur if flooding and stumping is conducted more than once every 3 years (Randall Mutters, Steve Butler, and Steve Rystrom, Personal communications).

Bird *et al.,* 2002 find evidence that rice straw incorporation leads to increased availability of nitrogen in the soil and increased nitrogen uptake by rice. They recommend that nitrogen application be decreased by 25lbs/acre when straw is incorporated and the field flooded during winter (Linquist *et al.*, 2009), or by at least 25 lbs/acre after 5 years of straw incorporation (Mutters *et al.,* 2007). Reduced nitrogen application can lower production costs and reduce the risk of water pollution (Bird *et al.,* 2002). Don Bransford argues that as long as burning is operated once every 4 to 5 years, disease pressure is not increased.

Compared to straw burning, straw incorporation does not lead to lower nitrogen losses (e.g., through leaching and N_2O emissions) (Bird *et al.,* 2005). Straw incorporation tends to increase the prevalence of grassy weeds, particularly water grass. However, this effect is mitigated with winter flooding (Bird *et al.,* 2005). Bird *et al.,* 2005 note that rice straw incorporation or rolling enhances carbon sequestration as soil organic matter accumulates and reduces GHGs in the atmosphere.

5. Development of costs and emissions data and model simulation scenarios

We have developed a set of representative cost budgets faced by a hypothetical rice grower in the Sacramento Valley when implementing a selected set of scenarios simulated in the DeNitrification-DeComposition (DNDC) crop growth model.

5.1 Development of cost budgets

The cost budgets are the result of discussions with rice growers and rice experts, and are based on previous cost and returns studies conducted by the UC Cooperative Extension. In particular, we used the 2007 study prepared by the University of California Cooperative Extension (Mutters et al. 2007), "Sample Costs to Produce Rice: Sacramento Valley, Rice Only Rotation" ("UCCE study") to serve as the basis for the representative cost budgets.

We updated the parameters in the budget and modified the cultural and post-cultural operations as described in the subsection below. All calculations were performed using the budget program provided by the UC Cooperative Extension in Davis. The equipment, seeds, fertilizer, pesticides, herbicides, and air application custom price data were all changed to reflect appropriate values for 2009. Air application rates were obtained from Bob's Flying Service. Susan Ricketts, Supply Division Manager for the Butte County Rice Growers Association, supplied February 2009 prices for fertilizers, herbicides, adjuvants, insecticides and fungicides. Baling costs, gasoline and diesel prices are the latest quotes from the UC Cooperative Extension. Other costs come from the 2007 UCCE study and are updated according to the National Agricultural Statistics Service's agricultural price index in *Agricultural Prices Summary*, where appropriate.

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Modifications to the list of equipment include the addition of a 225 HP 4wd Tractor, a 22' Rice Roller, and a 16'x30' Triplane. A ¾ ton pickup was removed from the UCCE study for these scenarios.

5.2 Estimation of GHG emissions

Our budget calculations per unit of rice or per unit of emissions rely on yield and greenhouse gas emissions data simulated with the DNDC model under the supervision of William Salas, Applied GeoSolutions. For each scenario, Salas ran the model for 6324 fields (modeling units). His DNDC simulations incorporate the issue of periodic burning for pest/disease management. For each field, Salas ran a 10 year simulation with one year having straw burning for disease management. The first 2 years of the simulation were discarded to initialize the crop litter pools, and the subsequent 8 years of results were averaged. So the 8-year average data, with one year including a burn, represents about 13 percent burning, which closely mirrors the current multi-year average.

The DNDC model provided estimates of emissions of methane (CH_4) and nitrous oxide (N_2O) and net carbon sequestration or change in soil organic carbon (dSOC) content. Adoption of the state's climate change regulation has motivated the evaluation of alternative growing practices.

The DNDC model estimates emissions from the soil, but does not include other sources of emissions such as from fossil fuel consumption or from rice straw burning. Furthermore, when rice straw is removed from the field (such as in baling operations), DNDC does not count any emissions from that straw, even though this straw may be left to decompose off the field. This study is not a life-cycle analysis. Energy inputs and emissions from such activities as fertilizer production, transportation or other off-field activities are not included.

Estimates of CH_4, N_2O and dSOC are converted to carbon dioxide equivalency (CO_2eq). The DNDC model provides yield estimates in kilograms of dry matter carbon per hectare. These values are converted into emissions per hundredweight (cwt) of rice by converting into total dry matter, assuming dry matter to be 40 percent carbon, and then converting to 14 percent moisture.

For this report GHG implications must be related to cost and revenue implications. Potential financial returns to growers from mitigating greenhouse gas emissions are calculated by using the data on GHG emissions to estimate the potential for growers to sell carbon offset credits under current and future emissions trading markets. Current market prices for carbon offset credits in terms of CO_2 equivalent tonnage were obtained from the Carbon Catalog (carboncatalog.org), an independent directory of non-profits and for-profit companies that market carbon credits.

5.3 Choosing scenarios to model

The baseline for the cost budget estimates is an update of the 2007 UCCE study. This baseline provides the point of comparison for all modeled scenarios.

Converting the biophysical scenario results into a format to which the cost study data may then be applied requires an arduous and time-consuming process. Thus the number of scenarios that

can be assessed was necessarily limited. In addition, as with all modeling efforts, the DNDC effort developed preliminary analyses that had to be evaluated and then refined before final versions of any scenario could be considered. Because of the nature of this process and because scenarios are combinations of practices, we chose to develop the economic analysis for seven of a very large set of possible scenarios.

The seven scenarios in addition to the baseline are:

(1) conventional cultural operations, and post-harvest operations with rice straw incorporation and winter flooding;

(2) conventional cultural operations, and post-harvest operations with rice straw incorporation without winter flooding;

(3) conventional cultural operations, and post-harvest operations with rice straw removal without winter flooding;

(4) conventional cultural operations, and post-harvest operations with rice straw removal and winter flooding;

(5) cultural operations including drill seeding, and post-harvest operations with rice straw incorporation and winter flooding;

(6) cultural operations including mid-season drainage at 35 days after planting; and

(7) cultural operations including mid-season drainage at 45 days after planting.

Discussions with rice growers and extension specialists indicate that most growers currently utilize practices similar to those in the baseline scenario. Practices outlined in scenarios 1 and 2 are simply the two straw handling procedures which are combined to create the baseline as a weighted average. Scenario 3 is used on some land by some growers. Scenario 4 occurs rarely because there is little reason to undertake winter flooding if the straw has been removed. Scenario 5 operations are undertaken by only a few California growers, but were expected to have some potential to reduce GHG emissions. Scenarios 6 and 7 represent practices that are very rarely utilized by growers in California, but are considered because experts believe that they may offer potential reductions in greenhouse gas emissions, especially methane emissions.

5.4 Explanation of simulated scenarios

Scenario 0: Baseline combination of rice straw incorporation with and without winter flooding

The baseline scenario reflects an attempt to update the 2007 UCCE study to 2009 conditions. It is the closest approximation to the current typical practices employed by growers in the Sacramento Valley. Prices in the baseline are updated from the 2007 UCCE study to 2009 values, but quantities of inputs (except where noted) remain the same as in the 2007 UCCE study. Relative price changes may therefore be a concern. For example, fertilizer use may

increase relative to other inputs with an increase in the price for rice because growers will utilize more yield increasing inputs. However, it is assumed that prices did not change enough to affect relative quantities, inputs are combined in fixed proportions and the production function is characterized by right angle isoquants. Although adjustments by growers are expected, we did not adjust here.

In the baseline scenario, we utilize many of the cultural operations as in the 2007 UCCE study. However, the application of several herbicides is modified to reflect new standard practices among rice growers due to new environmental regulations. Clincher and propanil products are now applied to 50 percent of acreage by air and 50 percent of acreage by ground (Mutters 2009). Grandstand is removed from usage. Harvest and post-harvest operations in the baseline are the same as in the 2007 UCCE study.

Scenario 1: Rice straw incorporation and winter flooding

Cultural and harvest operations are similar to the baseline.

Post-harvest operations are modified in scenario 1 to reflect incorporation of rice straw on the available acreage. Since the hypothetical rice grower, on average, burns 13 percent of their field for disease control, rice straw incorporation is operated on 87 percent of total field acreage. On 27 percent of total acreage, the paddy is flooded and rice straw is rolled with a cage roller. Chop and disc is operated on the remaining 60 percent of acreage on which rice straw is incorporated.

In the UCCE study, water for straw management is utilized on 23 percent of total acreage. Since some fields can be rain-fed, we set water for straw management to 60 percent of acreage to achieve winter flooding in scenario 1, with rain expected to provide water for the remaining 40 percent of acreage.

Scenario 2: Rice straw incorporation without winter flooding

Cultural and harvest operations are similar to the baseline.

Post-cultural operations are modified to achieve rice straw incorporation without flooding. Chop and disc are set at 87 percent of acreage, and flood and roll set to 0 percent since there is no post-cultural flooding. Fields are only rain-fed and there is no water cost for straw management.

Dry winters may accentuate microbial N immobilization and result in poorly decomposed straw in the spring, requiring a nitrogen fertilizer application increase of 10-15 lbs/acre in the next growing season. To account for precipitation variability over the long-term, we weight the increase by the number of dry years since 1989. Therefore, the initial fertilizer application consists of 138.57 lbs N/acre of aqua ammonia, 8.37 lbs more N per acre than in the baseline.

Likewise, dry winters may cause slower rice straw decomposition, so we increase the time for seedbed preparation proportional to the number of dry years since 1989 to account for

precipitation variability. Therefore, the time allotted to the finish disc operation increases by 28.6 percent.

Increased levels of straw residue may favor aggregate sheath spot, requiring a wider fungicide application (Quadris) in the spring. Therefore, air application of Quadris increases to 45 percent of the acreage and the total amount applied increases proportionally to 4.76 fl. oz/acre.

Scenario 3: Rice straw removal without winter flooding

Cultural operations are the same as in the baseline, except that the quantity of potash applied increases by 50 lbs/acre to 100 lbs/acre.

Harvest operations are similar to the baseline.

Post-cultural operations are modified so that there is no rice straw incorporation (no chop and disc, or flood and roll compared to the baseline scenario), and we add a $50 custom rent per acre for baling and bale removal. There is no winter flooding, so water for straw management is set to zero.

Scenario 4: Rice straw removal and winter flooding

Cultural operations are the same as in the baseline, except that the quantity of potash applied increases by 50 lbs/acre to 100 lbs/acre. Note that these values correspond to the hypothetical farm and more potash would need to be applied in lighter soiled areas.

Harvest operations are similar to the baseline.

The post-cultural operations are modified so that there is no rice straw incorporation (no chop and disc, or flood and roll compared to the baseline scenario), and we add a $50 custom rent per acre net of the rice straw sale for baling and bale removal. Like in the baseline scenario, we set water for straw management to 60 percent of the acreage for winter flooding.

Scenario 5: Drill seeding

Cultural operations are modified compared to the baseline, so that rice is drill-seeded instead of air broadcasted. Fields are flooded 26 days after planting. We remove the custom rents for air application of the seeds and the starter aqua ammonia. Instead, we include the purchase of a 20-foot wide drill-seeding piece of equipment and add 295 lbs/acre of urea (which is 46% nitrogen) to the initial fertilization operation. At 191.3 lbs N per acre, 5.5 lbs more N per acre is applied than in the baseline scenario. The hypothetical rice grower applies half of the urea by air and half by ground. Slightly more nitrogen is applied in drill-seeding systems compared to water-seeded systems to achieve similar yields.

Moreover, we include one additional tractor pass in the seedbed preparation to obtain a finer till. This involves increasing the time allotted to the finish disc operation by about 50 percent.

Drill-seeded systems require less water-based herbicide and somewhat more contact herbicide. The amount of Clincher applied is reduced by 75 percent from 14 fl. oz per acre to 3.5 fl. oz per acre. A new herbicide, Prowl, is added to the UCCE list to face the new weed population. It is applied by air at 16 fl. oz/acre.

Pest and fungus pressure are altered in drill-seeded systems, so we set the quantities of the insecticides Warrior and copper sulfate to 0.

Harvest operations are similar to the baseline scenario.

For post-harvest operations, 13 percent of the field is burned, and rice straw incorporation is operated on 87 percent of total field acreage. On 27 percent of total acreage, the paddy is flooded and rice straw is rolled with a cage roller. Chop and disc is operated on the remaining 60 percent of acreage on which rice straw is incorporated. Water for straw management is set to 60 percent of acreage for winter flooding.

Scenario 6: Mid-season drainage beginning 35 days after planting

Cultural operations are similar to the baseline, except for irrigation water. Mid-season drainage takes place over 14 days, starting from day 35 after planting, during which about 5 to about 7 acre-inches of water are saved (Mutters 2009) compared to the conventional water-seeded system (Mutters 2007).

Harvest operations are the same as in the baseline scenario.

For post-harvest operations, 13 percent of the field is burned, and rice straw incorporation is operated on 87 percent of total field acreage. On 27 percent of total acreage, the paddy is flooded and rice straw is rolled with a cage roller. Chop and disc is operated on the remaining 60 percent of acreage on which rice straw is incorporated. Water for straw management is set to 60 percent of acreage for winter flooding.

Scenario 7: Mid-season drainage beginning 45 days after planting

Cultural operations are similar to the baseline, except for irrigation water. Mid-season drainage takes place over 14 days, beginning on day 45 after planting, during which about 5.5 to about 8.5 acre-inches of water are saved (Mutters 2009) compared to the conventional water-seeded system (Mutters 2007).

Harvest operations are the same as in the baseline scenario.

For post-harvest operations, 13 percent of the field is burned, and rice straw incorporation is operated on 87 percent of total field acreage. On 27 percent of total acreage, the paddy is

flooded and rice straw is rolled with a cage roller. Chop and disc is operated on the remaining 60 percent of acreage on which rice straw is incorporated. Water for straw management is set to 60 percent of acreage for winter flooding.

6. Yields, cost and profit implications of model scenarios

Results are summarized over six variables that relate to farm or field output, costs, operating profits, emissions, market-wide production and emission, and response to GHG payments. First we consider yields and then go on to consider costs, revenues and net returns or operating profits per acre and per unit of rice produced. These impacts have implications for how much rice would be planted under alternative scenarios and under alternative prices for GHG emission reductions that may be offered by the market.

6.1 Yields

To provide a comparison for the model-projected yields, Panel A of Table 2 shows average rice yields in California rice region counties. These yields have typically been between 80 and 85 cwt per acre in recent years. Average yields have varied by county as well as over time.

Panel B of Table 2 shows bio-physical model yields by scenario from William Salas, who utilized the DNDC model to project yields based on soil and other characteristics for each rice field in the Sacramento Valley. A geographic information system (GIS) framework assigned each field to a county to facilitate comparison with the actual historical data. Notice the DNDC yields tend to be higher than the historical yields in some counties and lower in others, but that generally they are not too divergent from the reality of recent years.

The 2007 UCCE cost study used an average yield of 80 cwt per acre to calculate costs. However, Salas's simulations with the DNDC model, drawing upon a wide body of soil conditions and other information project a higher average model yield for the baseline and most other scenarios. The model yields in Panel B are generally higher than observed yields shown in Panel A. Yields from the DNDC model provided by Salas are calculated as the achievable biological yields, given soil and water conditions under practices specified. These yields are likely to overestimate actual yields because they do not reflect fully actual farmer behavior or other biophysical and market conditions that affect yields. For example, they do not reflect potential grower responses to high rice prices or high fertilizer prices.

For our calculations, the baseline employs a yield of 87.71 cwt per acre. As shown in Panel B of Table 2, yields are not much different between the baseline and scenarios 1 through 4. Cultural operations in scenarios 1 and 2 are the same as the baseline, and the extra 50lbs of potash applied in scenarios 3 and 4 are expected to compensate for the removal of rice straw, so that yields remain similar to the baseline. The DNDC results of Salas for drill seeding show a lower yield of 84.44 cwt per acre for scenario 5. The two mid-season drainage scenarios reduce yields considerably compared to the baseline. Using the DNDC model, Salas estimates a yield of 64.47 cwt per acre for scenario 6 and a yield of 71.93 cwt per acre for scenario 7.

To account for the difference in yield estimates from the DNDC model and the 2007 UCCE

study, yields could be adjusted downward by a ratio of each yield value to the maximum from the DNDC model, multiplied by 80 cwt per acre. For example, a downward shift of the yield value for scenario 5 would be (84.44/87.79) x 80 = 76.95 cwt. An alternative way to account for the difference between yield estimates would be to use the 2009 average yield for all rice in California, 86 cwt per acre, which would be between Salas's DNDC yield estimates and those used in the 2007 UCCE. However, overall results would not change much because relative differences between scenario costs would not change from the downward shift method. That is, what matters for comparing scenarios is mainly the relative yields across sets of practices and less the absolute yields.

In general, a more detailed set of bio-physical scenario models would calibrate yields more precisely to actual California conditions. The level of yield can become important in considering profits or net revenues and in comparing responses to GHG incentives under alternative rice prices.

6.2 Production costs

Simulations of various production practices yielded production costs for the baseline and the seven scenarios outlined above. The costs differ marginally for the baseline and the two scenarios upon which it is based. For other scenarios costs do vary and costs per acre have a different pattern than costs per cwt of rice.

As shown in Table 3a, scenario 5 has the lowest production costs per acre. However, it has relatively high costs per cwt of rice ($18.26 per cwt) due to the low expected yield for this practice. The two mid-season drainage scenarios, scenarios 6 and 7, also have low production costs per acre. Each of these scenarios has estimated production costs of $1557 per acre, below the baseline's estimated cost of $1572 per acre. However, due to lower estimated yields under mid-season drainage, these scenarios have high costs per cwt. Scenario 6 has costs of $24.15 per cwt, while scenario 7 has costs of $21.65 per cwt. Other scenarios have higher costs than the baseline with similar yields. Scenario 1 has costs of $1570 per acre or $17.90 per cwt. Costs are $1575 per acre or $17.92 per cwt for scenario 2. Production costs on a per acre basis are highest for those scenarios that employ baling operations. Scenario 3 has production costs of $1616 per acre or $18.39 per cwt, and Scenario 4 has production costs of $1622 per acre or $18.46 per cwt. Note that the UCCE cost studies do not include the costs of manager or operator time. A program that provides offset credits would require additional costs associated with verification and registration as well as additional time and effort by the operator or manager. Just as with costs of compliance with other government programs or rice marketing, because they are not associated with direct production activities, none of these costs are including here. To the extent that some scenarios require more management than others, the full costs of these scenarios will be underestimated.

6.3 Revenue Minus Operating Costs (Profits)

The ability for growers to make profits determines whether they will adopt a particular practice with no additional policy based revenue or mandatory regulation. Profits depend on growers' production costs and the market price of rice. For our calculations, we used the 2009 price for all

rice in California reported by the National Agricultural Statistics Service (NASS), which is $18.60 per cwt. We also considered an illustration in which the rice price is $8.00 per cwt and government payment per cwt is $1.00. The revenues we describe here do not include any returns to growers from selling any offset credits they may earn under a greenhouse gas mitigation scheme.

Eligible rice operations in California and other rice-producing states receive government rice policy payments from three related programs. The direct payment (DP) is not directly connected to current yield, current acres of rice or current market price. Direct payments vary by farm based on historical acreage and historical program yield on that farm. Direct payments are not directly "rice" revenue, except in a historical sense. For the $18.60 per cwt scenario and $8 per cwt illustration, we used the same payment yield and payment rate as those used in the 2007 UCCE study. The payment yield is 85 percent of growers' yields and the payment rate is $2.35 per cwt, for which 87 percent of rice acres are eligible. But, again this payment is not tied to current rice production and in this analysis we do not consider it to be revenue for the production of rice. In a longer run analysis growers may assess whether the government is likely to adjust payments under this program to reflect more recent rice acreage and yield.

The second program is the counter cyclical payment program (CCP). The CCP rate is determined by the national average price of rice, and by the target price ($10.50 per cwt). However, recipients are not required to grow rice to receive CCP and the quantity used for payment calculations is based on historical acreage and yield. Therefore, the CCP is not directly tied to current year acreage or yield and is only paid when market prices are low. With a market price of $8 per cwt, the CCP would be a significant contributor to farm income for most rice producers, but we do not include the CCP as a part of direct rice production revenues in what follows. The CCP payment has not been paid in recent years due to several years of strong rice prices.

The loan deficiency payment (LDP) for rice depends on the difference between the program loan rate (set at $6.50 per cwt) and the adjusted world price for rice. In recent years, the world price has been well above $6.50 and the LDP has been zero. At the alternative rice price of $8 per cwt that we use for illustration, we assume an adjusted world price of $5.50 so the LDP is $1 per cwt of rice production. As noted above, this payment is considered a part of rice production revenue because it depends on both the price of rice and the current production quantity on each farm.

The illustration using a price of rice of $8 per cwt is calibrated off of current acreage, not 2007 acreage. This illustration starts with current acreage and indicates the general effect that lower rice prices would have on revenues and through the scenarios on emissions and acreage under alternative emission market prices.

Subtracting production costs per cwt from these rice production revenue yields net operating profits. These scenario calculations use a price of rice of $18.25 per cwt, which is very high by historical standards and more than double the average of prices that prevailed before the recent price spike. As shown in Table 3a, profits per cwt are highest for scenario 1 at $2.44 per cwt. Profits per cwt are $2.43 for the baseline scenario and $2.42 for scenario 2. These practices are in widespread use currently. Whether a farm chooses winter flooding on a particular field depends on the expected profits from each set of practices for that field. The numbers shown in

the tables are for valley-wide averages.

Due to higher production costs from baling, average expected profits are significantly lower for scenarios 3 ($1.95 per cwt) and 4 ($1.88 per cwt) than the straw incorporation scenarios. Profits per cwt are $2.08 for scenario 5, which has a lower yield than the baseline, but also lower costs per acre. Scenarios 6 and 7 have negative revenue per cwt due to lower yields. Profits per cwt are -$3.81 for scenario 6 and -$1.31 for scenario 7.

7. Greenhouse gas emissions and profits with a market for emissions reductions

Under a set of conditions that foster the development of markets for GHG offsets in California and a verified set of protocols for rice, growers may be able to increase their profits by selling offset credits under a greenhouse gas mitigation scheme. Markets for such offset credits already exist and may become more established with greater regulation of climate changing activities.

Results from the DNDC model are shown in Columns (4) and (5) of Table 3a and indicate that scenarios 2 through 7 would offer reductions in greenhouse gas emissions per acre from cultural practices compared to the baseline. On a per acre basis, scenario 6 and 7 have the lowest emissions at 2.14 tCO_2eq, followed by scenario 3 at 2.73 tCO_2eq. These estimates do not include GHG implications of additional fuel use and implications of added cultivation needed, for example, when no winter flooding is used.

Table 3b reports estimated emissions from fuel use in each scenario and adds these to the other emissions. When emissions from fuel use are added, the relative ranking of scenarios by emissions does not change. However, ranking of scenarios by emissions changes when yields are considered and emissions are calculated on a per cwt basis.

On a per cwt basis, when fuel emissions are included, scenarios 3 and 7 have the lowest emissions at 0.034 tCO_2eq, followed by scenario 2 at 0.036 tCO_2eq. Scenario 2 has the highest emissions from fuel use, but this is offset somewhat by moderate overall emissions. Emissions in scenario 1 are still higher than the baseline.

Results from the DNDC model in Table 3b indicate that scenarios 2 through 7 offer mitigation potential per acre. However, revenues under scenarios 6 and 7 are estimated to be negative, so these scenarios would not be readily adopted. (Subsection 7.2 offers a special discussion for these scenarios.) Scenario 3 has the low per cwt emissions, but we estimate that profits are significantly lower than under the baseline or scenario 2. Practices under scenario 2 release about 0.26 tCO_2eq less per acre or 0.003 tCO_2eq less per cwt than the baseline, and profits are similar to the baseline. Emissions under scenario 3 are about 0.45 tCO_2eq per acre or 0.005 tCO_2eq per cwt lower than in the baseline, but profits are about 20 percent lower. Also, bear in mind that full emissions will likely be higher than indicated for scenario 3 because emissions from straw decomposition or other usage off the field are not recorded for scenarios with baling operations (see Section 5.2).

Scenario 2 is rice straw incorporation without winter flooding and employs the same cultural and harvest operations as the baseline. Initial nitrogen application is actually higher than in the baseline, but there is no post-cultural flooding. Greenhouse gas emissions in scenario 2 are about 8 percent lower per cwt than those in the baseline. Scenario 3 is rice straw baling without winter flooding and employs the same cultural and harvest operations as the baseline, except the quantity of potash applied is 50 lbs/acre higher. Emissions in scenario 3 are about 13 percent lower per cwt than those in the baseline.

Figure 2 uses the data from table 3a and 3b to depict average calculated operating profits per ton of GHG emissions for each scenario. The values are obtained by dividing column 3 in Table 3a by column 4 in Table 3b. Therefore the units are dollars of profit per ton of emission. Only scenario 2 has a higher value than the baseline, indicating that per cwt of output, this scenario will have higher operating profits per tCO_2eq of emissions than the baseline. Scenarios 1 and 3 have values close to the baseline, meaning that their operating profits per tCO_2eq of emissions differ only slightly from the baseline. Scenarios 4 and 5 have lower operating profits per tCO2eq of emissions, meaning that reductions will come at higher costs to producers if these practices were mandated and would require more compensation for farmers to break even. Scenarios 6 and 7 do not appear on the figure because their calculated operating profits are negative and therefore operating profits per tCO_2eq are also negative. As mentioned, it is for this reason that these scenarios would not be readily adopted voluntarily by producers without very substantial compensation..

Scenario 2 practices maximize the reduction in greenhouse gas emissions for the loss in producers' operating profits. The smaller the change in producers' operating profits, the smaller the payments for abatement needed to compensate producers for adopting the new practices. Therefore, the comparatively high operating profits per tCO_2eq of emissions for scenario 2 mean that this scenario will have the potential for GHG reductions at the lowest cost of the scenarios under consideration.

7.1 Greenhouse gas emissions and profits for rice straw incorporation without winter flooding and rice straw baling without winter flooding with a market for emissions reductions

We show the carbon credit prices for which the producers' revenues minus operating costs equals that found in the baseline. For these illustrations, we use a supply response such that the acreage changes by one percent for each one percent change in net revenue. This allows an assessment of how many acres of rice are drawn into production when the carbon credit price changes around the breakeven point, if that were allowed by the policy. Initial California rice production in the DNDC simulations consists of about 52.2 million cwt on 584 thousand acres.

The following tables show effects of alternative potential market prices for offset credits when the acreage devoted to rice adjusts to the projected net revenue per acre. In these tables, when the carbon price is above the breakeven point, acreage adjusts upward in accordance with the percentage gain in profit. When the carbon price is below the breakeven price, we assume the scenario practices continue to be required on all rice acreage, but acreage planted to rice adjusts downward in accordance with the percentage loss in profit per acre.

Table 4 shows changes from the starting point in rice production, acreage, and GHG emissions under various prices for abatement credits assuming all rice acreage adopts the practices associated with scenario 2 (rice straw incorporation without winter flooding). Profits between the baseline and scenario 2 reach a breakeven point when the price for abatement credits reaches about $3.67 per tCO$_2$eq. If the price of credits were higher, revenue would be higher relative to the breakeven point and growers would add acreage and rice production. The assumption underlying the increase in acreage is that growers would be allowed to receive payment for abatement for all acres that used the scenario, including new rice acreage. Under these assumptions, if scenario 2 were mandated and no payment for credits were allowed, rice acreage would be lower by 2,633 acres and associated reductions in rice production and emissions would follow. Alternatively, if the price of emissions were $10 per tCO$_2$eq, rice farmers would add 4,545 acres, if allowed, and this would mean total emissions from rice production would be lower than the baseline by 6.73 percent.

Table 5 shows the same information for scenario 3 (rice straw removal without winter flooding). Because of high costs of scenario 3, the breakeven price of credits for scenario 3 is $92.90 per tCO$_2$eq. This breakeven price is much higher than that for scenario 2 because per cwt profits for scenario 3 are significantly below the baseline. As with Table 4, a carbon credit price of $0.00 is included in the table. The changes in rice land, production and GHG emissions that result from a price of zero show the reductions that would take place if the relevant scenario were imposed by regulation, but no GHG offsets credits were marketable. In this case, using our assumption of constant percentage acreage change, 117,856 acres would leave rice production. In this case, of course, emissions from rice production would be far below the baseline simply because much less rice would be produced in California and that rice production would occur elsewhere. (The analysis does not include emissions from other uses to which the rice land would be put.)

Table 6 shows the total change in rice production, land use, and net GHG emissions at offset credit market prices for scenario 2 assuming a hypothetical rice price of $8/cwt. In this case, the breakeven price falls to $2.98 per cwt. The price of carbon equivalents that imply the same profits as the baseline is lower because rice forgone by the slightly lower yield in scenario 2 is worth less. However, the overall GHG emissions reduction at that price is still about 7.45 percent, because the same amount of rice acreage is engaged in scenario 2. (Note, measured farm profits are negative at the price of $8 per cwt.)

Table 7 replays the scenario 3 from Table 5, but now for the lower price of rice. At $8 per cwt of rice, the breakeven price of abatement of carbon equivalents falls to $79.26 because the rice yield loss is less costly to revenues than at the higher rice price. However, the overall GHG emissions reduction at this breakeven price remains about 13 percent.

The results in Tables 4 through 7 are not based on an empirical distribution of costs or emissions across fields. The adjustments in acreage follow from assuming that a one percent change in net revenue per acre causes a one percent change in acreage planted to rice.

As the price of abatement credits rise, rice production and acreage increase gradually because growers expand rice land at the expense of other crops and pasture use in the Sacramento Valley. Rice becomes more profitable relative to other crops under scenarios 2 and 3 with the availability of a market to sell carbon credits. Tables 4 and 5 show some representative values of net change in rice land acreage and rice output in California at various abatement prices when rice is $18.6 per cwt, while Table 6 and 7 show the same information when rice is $8 per cwt.

Of course this approach to rice acreage response to emission market opportunities is simplified in many ways, especially in not incorporating differences in costs and benefits of alternative practices on fields with different soil, microclimate, water costs, grower attributes and other characteristics.

7.2 Greenhouse gas emissions and profits for rice straw baling without winter flooding, drill seeding and mid-season drainage scenarios with a market for emissions reductions

Previous research (Li *et al.*, 2002; Qui, 2009) suggested that mid-season drainage could mitigate CH_4 emissions by breaking the anaerobic cycle. That motivated the inclusion of scenarios 6 and 7 in this study, even though these practices are rarely utilized by growers in California.

As shown in Tables 3a and 3b, GHG emissions from scenarios 6 and 7 are low on a per acre basis. On a per cwt basis, scenario 7 still has low emissions, but emissions for scenario 6 are moderate. Because of low yields per acre, as Table 3a shows, scenarios 6 and 7 are the only scenarios for which profits are negative, even at the very high price of rice incorporated in the scenarios. Yields for these scenarios are significantly lower than the baseline and other scenarios, so costs actually exceed revenues. Growers would require significantly higher payments for these practices compared to those in scenarios 2 and 3 to compensate them for these low yields.

Table 8 shows the breakeven carbon credit prices that prevail for scenarios 2 through 7. The carbon credit prices are those prices at which producers' revenues, including those from selling carbon credits, minus costs are the same as they would be under the baseline without the option to sell carbon credits. The table reports carbon credit prices and the corresponding overall reduction in GHG emissions at that price. Results are reported for scenarios with a carbon market using the computed costs and the 2009 U.S. average price for rice, as well as the 2007 UCCE costs and a hypothetical $8/cwt price.

As discussed in the context of Table 4, profits between the baseline and scenario 2 reach a breakeven point when the price for abatement credits reaches about $3.67 per tCO_2eq. The estimated GHG emissions reduction from a carbon market with this price per tCO_2eq would be about 7.45 percent. The breakeven point for scenario 3 is about $92.90 per tCO_2eq and this price would lead to a GHG emissions reduction of about 13 percent compared to standard practices. Scenario 5 has a breakeven price of about $259 per tCO_2eq, which would result in about a 7 percent reduction in GHG emissions.

Scenarios 4, 6 and 7 have much higher breakeven prices of carbon equivalents. Scenario 4 has a high price breakeven point because it emits relatively high amounts of GHG, and scenarios 6 and 7 have negative revenues minus operating costs.

As an illustration, Table 8 also shows calculated carbon credit prices if the market price of rice were $8 per cwt. At $8 per cwt, profits between the baseline and scenario 2 reach a breakeven point relative to the baseline when the price for abatement credits reaches about $2.98 per tCO_2eq and the associated GHG emissions reduction would still be about 7.45 percent. The breakeven point for scenario 3 is about $79 per tCO_2eq and the GHG emissions reduction is about 13 percent. Scenario 4 has a breakeven price of about $331 per tCO_2eq, which would result in about a 3 percent reduction in GHG emissions. Scenario 6 would have a breakeven price of $3147 while scenario 7 would have a breakeven price of about $635. Scenario 5 would have no breakeven price at $8 per cwt because profits would be higher for this scenario than the baseline at any carbon credit price. It should be noted that revenues minus costs are negative for all scenarios at $8 per cwt of rice and 2007 costs. Since operating profits are zero under the $8 price assumption, scenario 5 with low cost per acre is the scenario that minimizes losses.

Although breakeven points change between the $18.60 and $8 per cwt prices in Table 8, GHG reductions in percent terms do not. The shift in price of rice per cwt does not change the relative profitability between scenarios and the baseline. Therefore, at a price of $8 per cwt, each scenario will break even at a point with the same change in acreage as it does under the $18.60 price. Since the change in acreage and rice production will be the same at $8 and $18.60, the change in GHG will also be the same.

8. Conclusions

Rice is an important crop in the Sacramento Valley. Current production practices result in the emission of greenhouse gases, especially because rice emits more methane than crops that are not flooded. Using alternative production practices can lower these GHG emissions and the analysis presented here has compared the economic impacts of switching from current practices to these alternative practices, as outlined in a baseline and seven other scenarios.

Six of these alternative scenarios have greenhouse gas mitigation potential compared to the baseline scenario. Out of these scenarios, scenarios 2 and 3 have the lowest cost of abatement. As explained in section 7.2, the mid-season drainage scenarios (6 and 7) offer significant GHG emissions reductions, but costly yield reductions mean that payments for abatement would need to be very high, and similar GHG reductions can be achieved for far less cost with scenarios 2 and 3. Scenarios 4 and 5 offer moderate GHG emissions reductions compared to the baseline. However, the potential reductions under these scenarios come at a higher cost than those under either scenario 2 or 3. Scenario 2 can achieve reductions at lower cost (see tables 4 and 5). It should also be noted that emissions in scenario 3 do not include off-field decomposition/disposal of rice straw, as described in section 5.2.

Voluntary adoption of scenario 2 (rice straw incorporation without winter flooding) by the rice industry has already taken place in California. More widespread adoption may be possible, given that current and likely future prices in carbon markets in Europe and North America are

high enough to offset the slightly higher production costs. However, the analysis here has not incorporated how differences in costs or yields across fields and farms of different characteristics would affect of this scenario. Moreover, we have not incorporated the benefits of winter flooding in terms of wildlife habitat or farm revenue from providing hunting opportunities. The analysis presented here assumes a representative farm in the Sacramento Valley, with production practices employed throughout the region. Actual costs and revenues are heterogeneous across farmers in the California rice industry. Rice farms with the highest relative returns for scenario 2 compared to the baseline already use the practices, and farms with low costs of shifting would do so with little added incentive. These are all issues that warrant further research.

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Table 1: Rice production in the Sacramento Valley sub-basins, 1999-2000.

	Basin					
	Butte	Colusa	American	Sutter	Yolo	Total
Total planted	(acres)					
	135,090	198,989	97,169	51,783	11,599	**494,631**
	(acres)					
	75,760	60,247	38,459	16,368	3,699	**194,534**
Flooded	(percent)					
	56	30	40	32	32	**39**

Source: Fleskes et al. 2005.

Note: The flooded acres are estimated on 30 December 1999. Fleskes et al. (2005) show that 39% of rice fields were flooded in 1999-2000, while 61% were rain-fed. Randall Mutters suggests that now about 60% of the fields are flooded during winter.

Table 2:
A. Average Sacramento Valley rice yields and B, Model yields for the top seven counties, hundred-weight (cwt) per acre

A.								
Year	Butte	Colusa	Glenn	Placer	Sutter	Yolo	Yuba	Average in listed counties
2001	86.6	83.0	88.0	78.0	82.6	79.2	77.8	82.2
2002	90.2	82.0	85.4	79.4	85.4	76.2	79.6	82.6
2003	81.0	79.0	81.0	70.0	86.4	76.2	78.0	78.8
2004	91.4	84.0	92.0	74.0	86.2	76.6	81.0	83.6
2005	76.0	73.0	73.0	69.4	75.0	78.6	68.0	73.3
2006	82.4	81.0	81.2	79.0	83.0	71.8	75.6	79.1
2007	86.6	83.0	85.8	66.8	78.6	74.2	82.6	79.7
2008	88.0	84.0	88.2	54.6	84.0	70.0	88.0	79.5
2001-2008 average	85.3	81.1	84.3	71.4	82.7	75.4	78.8	79.9
B.								
Scenario	Butte	Colusa	Glenn	Placer	Sutter	Yolo	Yuba	Average in listed counties
Scenario 1: RI-NWF	85.42	89.20	89.10	85.39	87.31	88.53	89.02	87.71
Scenario 2: RI-NWF	85.45	89.22	89.11	86.54	87.31	88.61	89.02	87.90
Scenario 3: Baling-NWF	85.44	89.16	89.09	86.54	87.30	88.59	89.02	87.88
Scenario 4: Baling-WF	85.58	89.14	89.09	86.54	87.30	88.51	89.01	87.88
Scenario 5: Drill- seeding; RI-WF	83.85	85.95	85.91	80.72	85.69	80.96	87.98	84.44
Scenario 6: Mid-season drainage 35 DAP; RI-WF, MD A	75.14	73.68	71.09	46.36	65.78	70.48	48.80	64.47
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	79.11	81.24	77.77	55.68	72.58	78.40	58.70	71.93

Table 3a: Costs, yields, profits and average emissions for baseline and seven scenarios

Scenario	Total costs	Model yield	Model revenues minus costs	Average GHG emissions per acre without fossil fuel emissions	Average GHG emissions per cwt without fossil fuel emissions
	(1)	(2)	(3)	(4)	(5)
	($/acre)	(cwt/acre)	($/cwt)	(tCO_2eq/acre)	(tCO_2eq/cwt)
Scenario 0: Baseline	1572	87.79	2.43	3.13	0.036
Scenario 1: RI-WF	1570	87.71	2.44	3.31	0.038
Scenario 2: RI-NWF	1575	87.90	2.42	2.86	0.033
Scenario 3: Baling-NWF	1616	87.88	1.95	2.73	0.031
Scenario 4: Baling-WF	1622	87.88	1.88	3.07	0.035
Scenario 5: Drill-seeding; RI-WF	1542	84.44	2.08	2.88	0.034
Scenario 6: Mid-season drainage 35 DAP; RI-WF, MD A	1557	64.47	-3.81	2.14	0.033
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	1557	71.93	-1.31	2.14	0.030

Sources: (1) Authors' calculations based on Mutters et al. (2007); (2) from DNDC model results (Salas et al. 2010) in Panel B, Table 2; (3) authors' calculations based on (1), (2) and NASS (2010); (4) and (5) from DNDC model results (Salas et al. 2010.)

Table 3b: Average emissions from fossil fuel use and total GHG emissions for baseline and seven scenarios

Scenario	Avg. GHG emissions per acre from fossil fuel use (1)	Avg. GHG emissions per cwt from fossil fuel use (2)	Avg. total GHG [1] emissions per acre (3)	Avg. total GHG [2] emissions per cwt (4)
	(tCO_2eq/acre)	(tCO_2eq/cwt)	(tCO_2eq/acre)	(tCO_2eq/cwt)
Scenario 0: Baseline[3]	0.322	0.0036	3.45	0.039
Scenario 1: RI-WF	0.308	0.0035	3.62	0.041
Scenario 2: RI-NWF	0.332	0.0038	3.19	0.036
Scenario 3: Baling-NWF[4]	0.272	0.0031	3.00	0.034
Scenario 4: Baling-WF[4]	0.272	0.0031	3.34	0.038
Scenario 5: Drill-seeding; RI-WF	0.320	0.0038	3.20	0.038
Scenario 6: Mid-season drainage 35 DAP; RI-WF, MD A	0.303	0.0047	2.44	0.038
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	0.303	0.0042	2.44	0.034

[1] Table 3a column (4) plus Table 3b column (1)

[2] Table 3a column (5) plus Table 3b column (2)

[3] Baseline values not modeled in DNDC. Baseline practices and costs are calculated as 60% Scenario 1 values and 40% Scenario 2 values.

[4] GHG emissions from fossil fuel use during baling operations are not included

Sources: Authors' calculations and Salas 2010.

Table 4: Total change in rice production, land use, and net GHG emissions at select offset credit market prices for scenario 2

Market price of offset credits	Change in rice land	Change in production	Change in GHG emissions	Percent change in GHG emissions
($ per tC02eq)	(acres)	(cwt)	(tC02eq)	(percent)
0.00	-2,633	-235,379	-158,446	-7.86
0.50	-2,274	-203,293	-157,301	-7.81
1.00	-1,915	-171,207	-156,155	-7.75
2.00	-1,197	-107,034	-153,863	-7.64
3.67	0	0	-150,041	-7.45
4.00	238	21,311	-149,280	-7.41
5.00	956	85,483	-146,989	-7.29
10.00	4,545	406,345	-135,531	-6.73
20.00	11,722	1,048,070	-112,616	-5.59

Source: Authors' calculations using data from Tables 3a and 3b and an acreage response elasticity to net revenue per acre of 1.0.

Rice land adjustments assume all land uses scenario 2 and rice acreage adjusts to the economic incentives provided by net revenue from rice and selling credits at the price listed in the first column.

Table 5: Total change in rice production, land use, and net GHG emissions at select offset credit market prices for scenario 3

Market price of offset credits	Change in rice land	Change in production	Change in GHG emissions	Percent change in GHG emissions
($ per tC02eq)	(acres)	(cwt)	(tC02eq)	(percent)
0.00	-117,856	-10,346,594	-617,229	-30.63
1.00	-116,588	-10,235,217	-613,425	-30.44
2.00	-115,319	-10,123,840	-609,622	-30.25
3.00	-114,050	-10,012,463	-605,819	-30.07
4.00	-112,781	-9,901,086	-602,016	-29.88
5.00	-111,513	-9,789,709	-598,213	-29.69
10.00	-105,169	-9,232,824	-579,197	-28.74
20.00	-92,483	-8,119,054	-541,166	-26.86
40.00	-67,109	-5,891,514	-465,103	-23.08
60.00	-41,736	-3,663,974	-389,040	-19.31
92.90	0	0	-263,927	-13.10

Source: Authors' calculations using data from Tables 3a and 3b and an acreage response elasticity to net revenue per acre of 1.0.

Rice land adjustments assume all land uses scenario 3 and rice acreage adjusts to the economic incentives provided by net revenue from rice and selling credits at the price listed in the first column.

Table 6: Total change in rice production, land use, and net GHG emissions at select offset credit market prices for scenario 2 with a hypothetical rice price of $8/cwt.

Offset credit market price	Change in rice land	Change in production	Change in GHG emissions	Percent change in GHG emissions
($ per tC02eq)	(acres)	(cwt)	(tC02eq)	(percent)
0.00	-1,073	-95,908	-153,466	-7.62
0.50	-893	-79,839	-152,892	-7.59
1.00	-713	-63,770	-152,318	-7.56
2.00	-354	-31,632	-151,171	-7.50
2.98	0	0	-150,041	-7.45
4.00	365	32,644	-148,876	-7.39
5.00	725	64,781	-147,728	-7.33
10.00	2,522	225,471	-141,990	-7.05
20.00	6,116	546,849	-130,514	-6.48

Source: Authors' calculations using data like that in Tables 3a and 3b but for a market price of $8 per cwt and a government payment of $1 per cwt. Acreage response elasticity to net revenue per acre is 1.0.

Rice land adjustments assume all land uses scenario 2 and rice acreage adjusts to the economic incentives provided by net revenue from rice and selling credits at the price listed in the first column.

Table 7: Total change in rice production, land use, and net GHG emissions at select offset credit market prices for scenario 3 with a hypothetical rice price of $8/cwt.

Offset credit market price	Change in rice land	Change in production	Change in GHG emissions	Percent change in GHG emissions
($ per tC02eq)	(acres)	(cwt)	(tC02eq)	(percent)
0.00	-49,668	-4,440,851	-412,820	-20.49
1.00	-49,042	-4,384,822	-410,941	-20.39
2.00	-48,415	-4,328,792	-409,063	-20.30
3.00	-47,788	-4,272,762	-407,184	-20.21
4.00	-47,162	-4,216,733	-405,306	-20.11
5.00	-46,535	-4,160,703	-403,427	-20.02
10.00	-43,402	-3,880,556	-394,034	-19.56
20.00	-37,135	-3,320,261	-375,249	-18.62
40.00	-24,602	-2,199,671	-337,678	-16.76
60.00	-12,069	-1,079,080	-300,107	-14.89
79.26	0	0	-263,927	-13.10

Source: Authors' calculations using data like that in Tables 3a and 3b but for a market price of $8 per cwt and a government payment of $1 per cwt. Acreage response elasticity to net revenue per acre is 1.0.

Rice land adjustments assume all land uses scenario 3 and rice acreage adjusts to the economic incentives provided by net revenue from rice and selling credits at the price listed in the first column.

Table 8: Calculated carbon credit prices for scenarios 2 through 7 at which producers' revenues minus costs are the same as the baseline; with a carbon market using 2009 U.S. average price[1] and costs[2] and hypothetical $8/cwt price and 2007 costs[3]

| Scenario	2009 U.S. price for rice ($18.60/cwt)		Hypothetical $8/cwt price for rice	
	Breakeven price	Reduction in GHG compared to baseline	Breakeven price	Reduction in GHG compared to baseline
	($/tCO$_2$eq)	(percent)	($/tCO$_2$eq)	(percent)
Scenario 2: RI-NWF	3.67	-7.45	2.98	-7.45
Scenario 3: Baling-NWF	92.90	-13.10	79.26	-13.10
Scenario 4: Baling-WF	435.24	-3.11	331.47	-3.11
Scenario 5: Drill-seeding; RI-WF	259.28	-7.16	No breakeven point. Scenario 5 revenue minus costs is higher than baseline's at any carbon credit price	
Scenario 6: Mid-season drainage 35 DAP; RI-WF, MD A	4391.79	-29.22	3147.16	-29.22
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	701.98	-29.17	635.47	-29.17

Sources: Authors' calculations from Table 3a and hypothetical $8/cwt price and costs from 2007 UCCE study
[1] The market price of $18.6/cwt is from NASS 2010.
[2] From Table 3a
[3] From UCCE cost study cited.

Figure 1: Rice-planted area in the Sacramento Valley, California. Basins in the north Central Valley where rice planted area was mapped using satellite image taken on 23 July 1999.
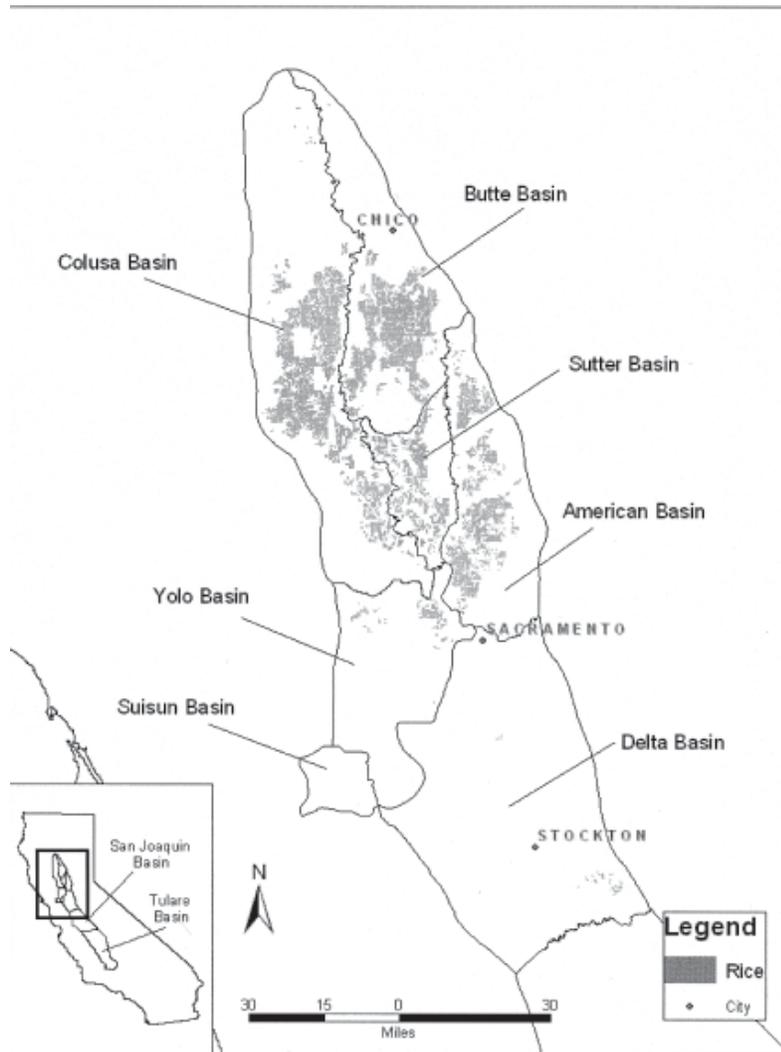
Source: Fleskes et al. 2005

Figure 2: Calculated operating profits per ton of CO_2eq emissions, by scenario
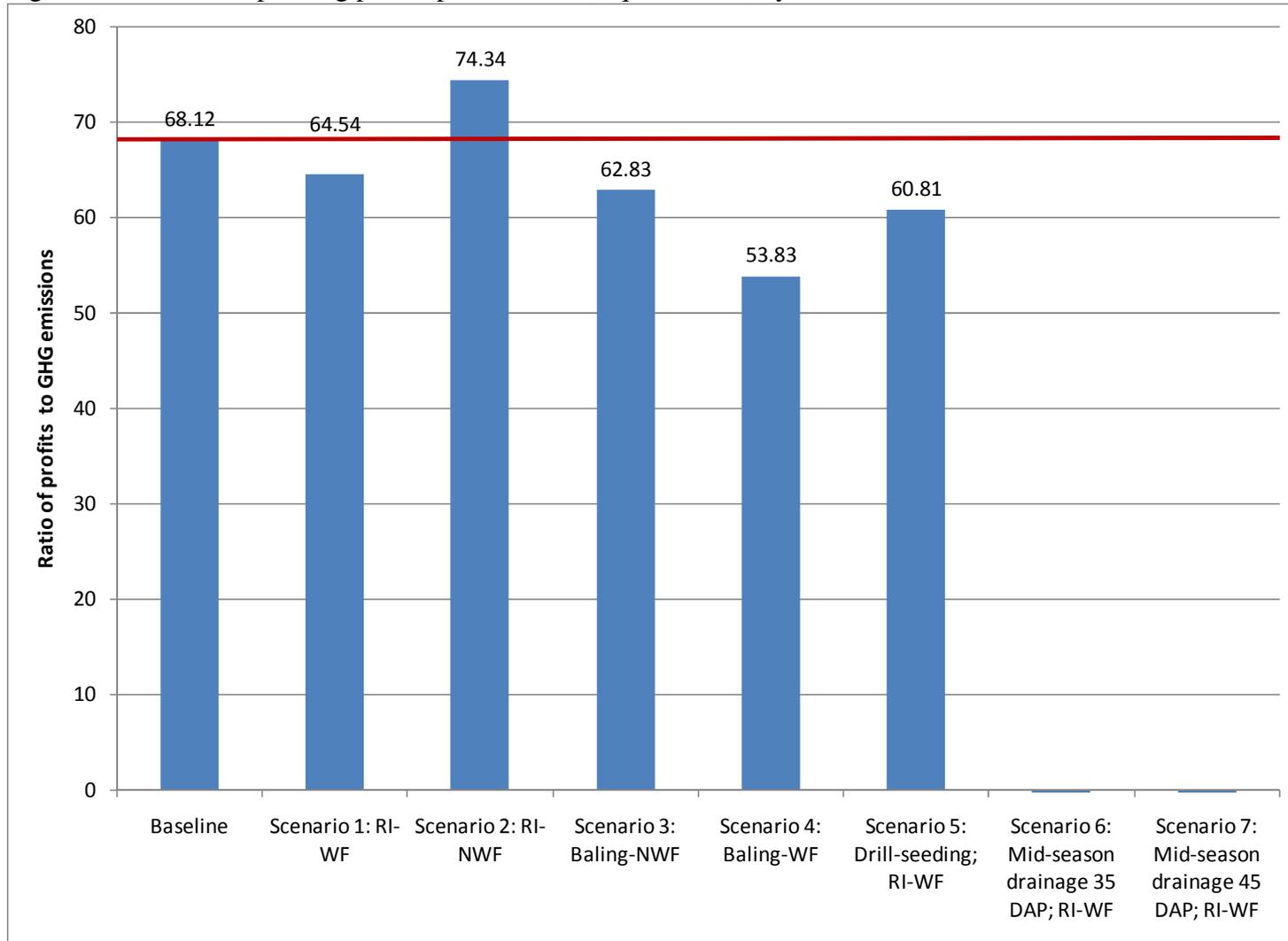
Source: Authors' calculations obtained by dividing column 3 in Table 3a by column 4 in Table 3b.