FINAL REPORT:

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Project Title: **Creating and Quantifying Carbon Credits from Voluntary Practices on Rice Farms in the Sacramento Valley: Accounting for Multiple Benefits for Producers and the Environment**
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INTRODUCTION

California rice is a highly significant crop for the state and the nation. California is the second largest rice producing state in the United States, producing rice on approximately 500,000 acres and contributing $1.3 billion to the state's economy. In addition, California rice is important to the world rice market, which received 43% of California rice in 2002[1]. The California rice industry also makes environmental contributions by providing critical habitat for migratory waterfowl for 230 wildlife species and 60 percent of the total number of waterfowl in the Pacific Flyway that use rice fields for habitat and foraging. These rice fields are designated as Shorebird Habitat of International Significance and provide over half of the food consumed by wintering waterfowl in the Sacramento Valley. It is estimated that if the amount of winter flooding of rice fields were to be reduced by 50 percent, there would be 1.2 million fewer ducks in the Sacramento Valley. This wintering habitat is estimated to provide more than $1.5 billion in habitat value for wintering waterfowl alone. Benefits to other categories of wildlife, such as shorebirds, wading birds, raptors and Giant Garter Snake also exist but are not easily quantified at this time[2].

Like other agricultural sectors, rice farms both emit and sequester greenhouse gases (GHGs). However, rice farms are faced with a unique challenge. Instead of burning, farmers eliminate rice straw by incorporating the straw into soils, flooding the fields, and allowing anaerobic fermentation to break down the organic material. The transition from burning to other non-burning management options has resulted in reductions in several criteria pollutant emissions (oxides of nitrogen/sulfur, carbon monoxide and particulate matter) but has increased GHG emissions. However, the by-product of straw fermentation is methane, which is 20 times more potent as a GHG than CO2, the by-product of rice burning.

California set a goal to reduce the state's greenhouse gas (GHG) emissions with the enactment of Assembly Bill 32 (AB 32, the Global Warming Solutions Act) in 2006. California agriculture is a relatively small contributor to statewide GHG emissions and it is not subject to the mandatory cap on overall industry emissions. As it stands, cap-and-trade regulations will allow offset credits to be used for compliance (up to 8 percent) and the Air Resources Board (ARB) will be working with qualified third-party offset programs to bring new projects into the offset system. Hence, the agricultural community has the potential opportunity to benefit from AB32 and voluntary carbon markets by participating in emissions trading markets through the sale of GHG offsets. This participation could provide a financial incentive to voluntarily reduce GHG emissions and sequester carbon in vegetation and soils.

Environmental Defense Fund (EDF), in partnership with the California Rice Commission (CRC), was awarded a USDA Conservation Innovations Grant in 2007 to explore and identify management practices that reduce GHG emissions from rice fields without negatively affecting yields. Project partners and other stakeholders have used this information, along with rigorous

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[1] Sumner, Daniel A., and Henrich Brunke. "The Economic Contributions of the California Rice Industry." California Rice Commission. September 2003. http://www.calrice.org/Economics/Economic+Contributions.htm
[2] Petrie, Mark, and Kevin Petrik. "Assessing Waterbird Benefits from Water Use in California Ricelands." Ducks Unlimited. May 2010. http://www.calrice.org/pdf/DucksUnlimited.pdf

science-based models and stakeholder input to develop high standard GHG protocols to account for GHG reductions and lay the groundwork for rice producers to voluntarily generate carbon offset credits.

The project outputs include the following: (1) a description of current farming management practices; (2) identification of innovative management practices and utilization and further validation of the DeNitrification-DeComposition (DNDC) model; (3) identification of the environmental co-benefits of the alternative management practices; (4) a GHG-reduction pilot project on a working rice field; (5) an analysis of the economic and operational feasibility of implementing voluntary GHG emission reduction practices; (6) a user-friendly version of DNDC for rice; and (7) a GHG quantification protocol resulting from any promising new practices.

EXISTING PRACTICES[3,4]

The standard rice farming procedure includes preparing the fields, flooding and seeding, harvesting, milling, and storing.

Field Preparation

Farmers prepare their fields for planting in April. First, fields are leveled using laser-guided grading equipment about every 5 years. Flat fields help ensure even distribution of water, uniform water depth, improve the efficiency of farm equipment, and facilitate management practices for stand establishment, weed control, and field drainage for harvest. Fields are tilled with a chisel to break up soil clods and to aerate the soil, followed by discing to reduce clod size and then smoothed out with laser-directed bucket scrapers. Liquid and dry fertilizer and pesticide applicators are often attached to the roller to allow growers to perform multiple operations at one time. The fields are typically planted from late April through May.

Flooding and Seeding

Water is run into the fields to a depth of 4 to 5 inches. Water depth is controlled by rice boxes (weirs) placed in levees and is increased or decreased by adding or removing “flash” boards in the boxes. Consistent water depth helps control weeds and reduces the need for herbicides. Shallow water promotes rice growth and rice seedling root anchorage, but also favors weed growth. Deeper depths (7 to 8 inches) delays early season growth, but also inhibits weed growth. The standard practice of a continuous flood of 4 to 5 inches provides good stand establishment, and coupled with herbicide application, good weed suppression.

Rice seed is soaked in water for 24-48 hours and then drained. Soaking initiates germination and increases the weight of the seed to minimize floating seeds and encourage the even distribution in the field when planted. Seeds are sown by airplanes into flooded fields at a rate of about 150 lb/acre. The heavy seeds sink into the furrows and begin to grow.

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[3] “California Rice: A Circle of Life in Every Grain.” August 2004. California Rice Commission. http://www.calrice.org/pdf/Informational+Brochures/Brochure_Overview_72.pdf (accessed March 1, 2010).

[4] Randall Mutters (UC Cooperative Extension, Butte County) provided input on practice definitions and environmental benefits for this report.

Rice Growth and Development

Early in the growing cycle, one to two applications of herbicides are applied to control weeds. If necessary, farmers may also treat the fields for insects. The rice plant grows rapidly, ultimately reaching a height of three feet. Rice is an aquatic plant, so farmers are careful to maintain a consistent water depth of the same 4-5 inches as the rice plant grows. Water depth is commonly raised to eight inches or more soon after panicle initiation about 60 days after planting. This is done to protect the developing pollen grains from night time temperatures. Prolonged exposed to low temperatures sterilizes the pollen. By late summer, the grain begins to appear in long panicles on the top of the plant. Growers reduce or eliminate water flow about five weeks before harvest, allowing water in the field to subside in preparation for drainage and the upcoming harvest. By September, the grain heads are mature and ready to be harvested. In general it takes rice about four- to five-months to mature.

Harvest

Farmers drain the fields before harvest. The timing of drainage is critical. If drained too early, the grain fails to mature. Immature kernels break or crack in the harvester, producing low-quality milling yields. Draining too late will leave the soils muddy and reduce harvesting efficiency. Growers also carefully monitor the moisture in the grain before harvesting. Rice harvest commonly begins when kernel moisture content reached around 21%. Optimal harvest moisture content for good milling quality varies by variety. High moisture grain requires excessive drying costs at the mill. Grain that is too dry may reabsorb water during periods of high nighttime humidity and develop cracks, which reduce grain quality and value.

Once the rice grain reaches the desired moisture content, the fields are harvested with a combine. The combine equipped with either a sickle bar or stripper header. The first cuts the rice plant itself and then separates grain from the straw internally. In contrast, the stripper header uses a toothed rotating drum to strip grain off the stalk, allowing stalks to remain standing in the field. The stripper allows for faster harvesting speeds but requires a second operation after harvest to then cut the straw. As the combine's grain tank fills with grain, specialized tractors called bankout wagons come alongside to receive the rice from the combines and subsequently deliver it to waiting transport trailers. The harvesters continue cutting rice without having to stop to unload. Each acre yields an average of over 8,000 pounds of dry rice (14% moisture content).

Post-Harvest

The rice straw remaining after harvest interferes with soil preparation for the next growing season, may delay planting, and can contribute to other production problems. Burning rice straw had been the standard management practice for decades. However, California law required that burning be significantly phased out starting in 1992 to reduce impacts of rice straw burning. Today, rice growers may burn, on a limited basis, for disease-control purposes. The program used to confirm the presence and extent of diseases is called the Conditional Rice Straw Burning Program.[5] This amount of burning is also conducted in strict accordance with the highly successful Sacramento Valley Smoke Management Program. A key component of the Smoke Management Program is a network of approximately 20 meteorological monitoring stations

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[5] "Burning Phase Down Law." California Rice Commission.
http://www.calrice.org/Environment/Air+Quality/Burning+Phase+Down+Law.htm

owned and operation by the California Rice Commission. This data is shared with all state and local air quality officials to enable them to determine the best days, times and locations to permit all agricultural burning in the Sacramento Valley in manner that minimized impacts to neighboring urbanized areas.

There are two common methods of soil incorporation to manage rice straw. First, non-flooded systems require tilling in the fall and winter rainfall for moisture. The straw may or may not be chopped before it is incorporated into the soil. The degree of straw decomposition is mainly determined by rainfall and temperature and to some extent grower management practices, making decomposition rates variable between years. Second, the winter-flooded system differs in that floodwater is introduced to the field shortly after harvest is completed and maintained until spring. The straw may or may not be prepared by chopping or soil incorporating before flooding. Decomposition of straw in this system is not limited by moisture and there is more complete decomposition compared to non-flooded systems.

Milling and Storage

After harvest, the rice is transferred to a commercial drying facility where it is dried to an ideal moisture level and stored as paddy rice until the customer places an order. At the mill, the hull is removed, leaving brown rice. White rice is the result of removing the bran layers in the milling process to leave just the inner portion of the grain.

Other Management Options

While this represents the typical management practices, there can be variations across fields. Differences occur with seeding practices, nutrient additions, water management, pest control, rice straw management and wildlife conservation practices.

Crop Rotations: About 30 percent of California rice is grown in rotation with other crops, and 70 percent is in rice/rice or rice/fallow rotation. This can subsequently affect how and when fields are seeded and drained, and other management decisions.

PRACTICES WITH GHG BENEFITS

Three experimental practices related to water management and soil organic-matter balance were tested during this CIG project. Water management in rice systems is one of the most important factors affecting CH4 emissions[6]. The amount of crop residue is one of the major factors for the soil organic-matter balance, which determines CH4, soil CO2, and N2O emissions[7]. Other practices that alter the soil environmental conditions may also affect soil carbon processes.

Mid season drainage: The practice of draining paddy fields in the middle of rice-growing season allows soils to dry and reduce methanogenic activity. In parts of Asia, where the practice

[6] US EPA. "Global Mitigation of Non-CO2 Greenhouse Gases." EPA 430-R-06-005. June 2006. http://www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf

[7] Li, C., W. Salas, B. DeAngelo, and S. Rose. "Assessing Alternatives for Mitigating Net Greenhouse Gas Emissions and Increasing Yields from Rice Production in China Over the Next 20 Years." Journal of Environmental Quality. 2006.

has been widely adopted, it has been known to increase rice yields, reduce water usage, and decrease methane emissions. On a very limited scale, this practice has been tested in California.

Straw management:

Straw incorporation: After the rice is harvested, rice straw (either chopped or not) remaining in the field is incorporated into the soil. The fields are then re-flooded to aid in straw decomposition, which leads to the creation of methane emissions.

Straw removal: After the rice is harvested, the rice straw is removed from the field. There are about 4 tons per acre of rice straw produced every year. A limited amount of straw is currently baled and sold for composting, livestock feed and bedding, and for erosion control at construction sites. Such a small percentage is actually used because the costs of removing, storing, and transferring straw are too high to enable the economic viability of other known uses. Taking the straw off the fields reduces the need for flooding post-harvest, and thus reduces methane emissions from anaerobic decomposition. However, rice straw contains a considerable amount of certain nutrients, such potassium. Therefore if straw is removed from the field, the addition of certain affected nutrients is required for continued rice production. Straw that is decomposed off-site must be done so aerobically to prevent indirect methane emissions.

Drill seeding: Drill seeding refers to the method of planting that utilizes grain drills or other planting equipment that places or drops seed into the ground slightly below the surface. It is also commonly referred to as "dry" seeding since nearly all rice planted in California is water seeded.

Drill seeding is adaptable to no-till, minimum till, or conventional tillage programs. Conventional tillage practices are the preferred methods of field preparation in California rice production. Typical equipment used for this activity includes field cultivators and spring chisels for opening the ground up, followed by disc harrows and some sort of land-planing tool (tri-plane, grading board, vari-track) used to level the field and ready it for planting.

Fertilizer is applied in split applications—one at planting, a second when permanent flood is established, and the final application immediately before the rice heads emerge. Typical equipment used for this activity includes applying the dry fertilizer with the grain at planting, using a separate hopper, or "box" in the planter. A self-propelled broadcaster can also be used in conjunction with the planter. Once permanent flood is established, an airplane is used to broadcast the fertilizer over the field.

PROJECT ACTIVITIES

EDF and CRC launched this partnership in September of 2007 seeking to answer a series of basic questions:

1. What are the economically viable management practices that California rice growers can implement to reduce greenhouse gas emissions?
2. How can we quantify those reductions in a cost effective way?
3. How can we create opportunities for growers to benefit from emerging GHG reduction markets?

While we benefited in from field research that had been conducted by researchers at the University of California and the California Rice Research Board, this research, covering aspects of methane and nitrous oxide emissions from rice, had not been organized in a format to answer our questions. Our activities were organized to systematically answer these questions.

Literature review and expert consultation

We assembled a group of expert technical advisors to provide input throughout the project (See Appendix A). We initially asked them to help identify all published studies relevant to answering our key questions and to validating the DNDC model. This group was also instrumental in creating a profile of the California rice production system, a system that is quite distinct from rice cultivation in other parts of the US and the world. The project team conducted several site visits to rice operations and consulted with growers in the field. CRC consulted regularly and received feedback from their Industry Affairs Committee which is comprised of prominent rice growers and processors.

Modeling

A significant portion of the activities of this project involved validating the DNDC model for the California rice production system. This process involved collecting substantial volumes of data about California's rice cultivation system, soils, and climate. The model was then run thousands of times to compare results against published studies. Modifications to the inner workings of the model were made to result in a more precise prediction of carbon and nitrogen behavior in the California rice system.

Determination of GHG mitigating activities

The validated DNDC model allowed us to run virtual field trials to determine the range of activities that would theoretically provide GHG mitigation benefits. Modelers were able to change various management factors in the model, run the model, and gain an accurate understanding of the impact of management changes on GHG emissions and carbon storage. These factors include timing and depth of flooding, planting date, method of planting, and rice straw management.

Field trials and determination of feasibility

Some of the practices that theoretically provide GHG benefits are novel for California rice (e.g., mid-season drainage) and others are implemented by some growers already (e.g. drill seeding, baling of rice straw). For the existing practices, we assessed feasibility by consulting technical experts and growers who had already implemented the practice. In the case of mid-season drainage, the practice had not been implemented in California so we recruited a grower to conduct a field trial. Because the practice involved crop risk, we agreed to provide the grower compensation for any yield loss. Results of this field trial were detailed in progress reports to NRCS in October and December 2009. Because there were no replicate trials, the results are not statistically significant and further trials are necessary to validate the DNDC model for the mid-season drainage practice.

Economic evaluation

UC Davis took the lead in conducting an economic analysis of the various GHG mitigating activities. This analysis included costs, yields, profits, and average emissions for baseline and seven scenarios as detailed in the "Economic Summary" section. The full analysis as a stand-alone document can be found in Appendix B.

Analysis of co-benefits and environmental tradeoffs

This analysis was conducted primarily through literature review and consultation with experts and growers. Results of this consultation and analysis can be found in the "Practice Benefits and Tradeoffs" section.

FUNDING RECEIVED AND EXPENDED

See attached SF-269 and final SF-270.

RESULTS

Technical summary

The projected modeling was conducted by Bill Salas (Applied Geosolutions, LLC.). DNDC was used to assess a variety of management practices impact on net GHG emissions. These management practices focused on alternative water and rice residue management. The 12 scenarios are summarized in Table 1. The soils and climate databases were used to run each management scenario for each of the over 6300 fields in the GIS database.

Table 1: Rice management scenarios modeled with DNDC

NWF Res Incorporation	**No winter flooding with residue incorporation**
NWF Straw Removal	**No winter flooding with residue removal**
NWF MD A	**No winter with midseason drainage for 14 days starting at 35 DAS**
NWF MD B	**No winter flooding with midseason drainage for 14 days starting a 45 days after seeding (DAS)**
NWF DS	**No winter flooding with drill seeding followed by flooding 26 days after seeding**
NWF Surface	**No winter flooding with residue mulched on surface following harvest.**
WF Res Incorporation	**Winter flooding with residue incorporation**
WF Straw Removal	**Winter flooding with residue removal**
WF MD A	**Winter flooding with midseason drainage for 14 days starting at 35 DAS**
WF MD B	**Winter flooding with midseason drainage for 14 days starting a 45 days after seeding (DAS)**

WF DS	**Winter flooding with drill seeding followed by flooding 26 days after seeding**
WF Surface	**Winter flooding with residue mulched on surface following harvest.**

The most common current management practice for rice production systems utilizes continuous flooding during the rice growing season with crop residue soil incorporation followed by winter flooding to enhance decomposition of the straw. The second most common production systems use residue incorporation without winter flooding. Based on current practices, approximately 60% of growers use winter flooding with residue incorporation and 40% use residue incorporation with no winter flooding. Thus we define "baseline" conditions as a combination of these two water management and residue management practices. Under this "baseline" management scenario, average methane emissions from California rice fields is approximately 264 kg C- CH_4/ha. Methane is the dominant greenhouse gas for rice systems. Modeled emissions varied considerably across fields and ranged from 165 to 837 kg C- CH_4/ha. Average nitrous oxide emissions were 1.3 kg N-N2O/ha. Under this management scenario, rice fields were on average a small soil carbon sink (~237 kg C/ha). Soil carbon sequestration varied from -10 to 447 kg C/ha. Accounting for all three greenhouse gases, average net GWP was ~7,400 kg CO_2eq/ha. The primary driver behind the variability in modeled emissions was soil texture. Figure 1 presents the histogram of modeled net GHG emissions for the winter flooding with residue incorporation management scenario. Figure 2 presents the values for each of the 6325 fields modeled.

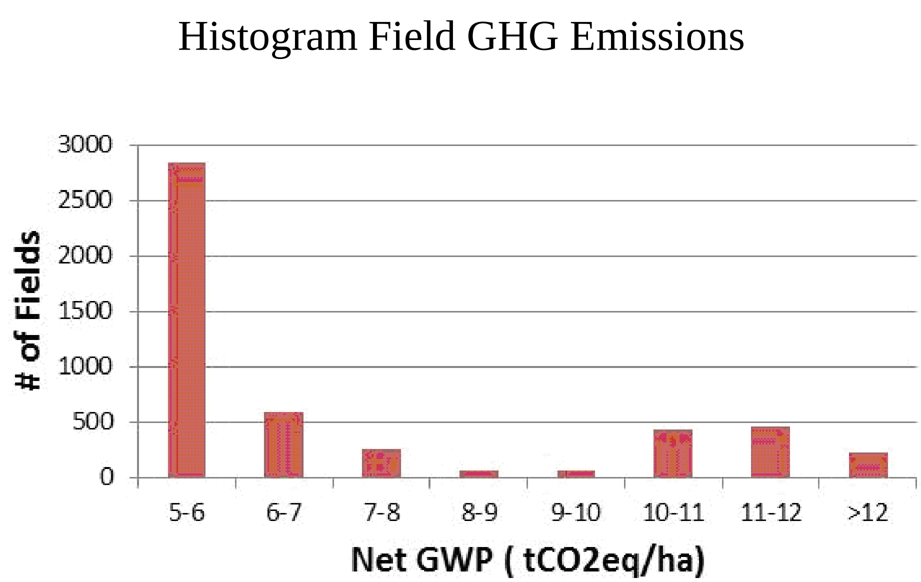

Figure 1. Variability in modeled GHG Emissions for management in season flooding, residue incorporation and winter flooding.

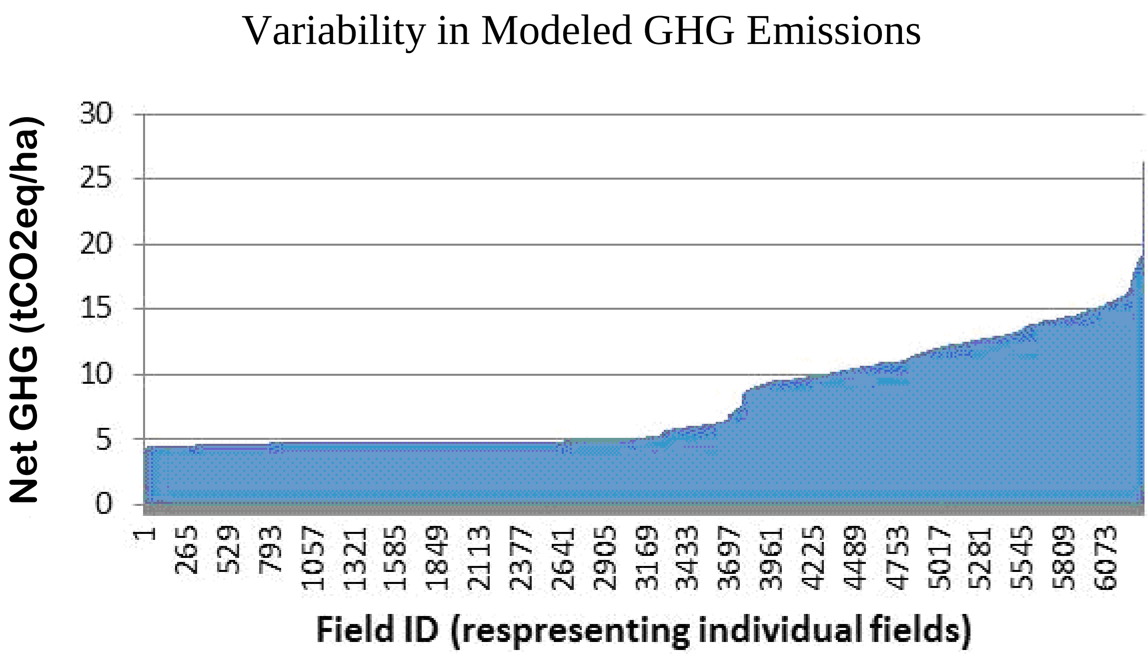

Figure 2. Field level net GWP for baseline management rank ordered from low to high per hectare emissions).

Table 2 and Table 3 provide summary results for each of the management scenarios. Across these management scenarios, average per hectare emissions ranged from 120 to 305 (kg C-CH_4/ha). Average nitrous oxide emission ranged from 0.9 to 1.6 kg N_2O/ha. For all scenarios without straw removal, the fields appear to be slight sink for soil organic carbon, with rates ranging from 63 to 326 kg C/ha. On a per hectare basis, the average net GHG emissions for these scenarios varied from 3.5 to 8.2 tCO_2eq/ha. The baseline management is listed first in each table followed by the management systems with the largest biophysical opportunity for reductions in net GHG emissions. Removal of rice residue (Straw Removal scenarios) would shift rice fields from small net sink of carbon to a new source, but both scenarios result in a net GHG reduction due to decreased methane emissions. The mid-season drainage provides the largest opportunity for reductions in CH4 and total greenhouse gases. Average mitigation opportunities relative to baseline emissions range from 0.3 to 3.6 tCO_2eq/ha (0.1 to 1.5 tCO_2eq/acre).

Table 2. Summary model results for management scenarios in units of Kg C/ha or N/ha.

	Yield (kg C/ha)	**CH_4 (kg C/ha)**	**Soil C Sequestration (kg C/ha)**	**N_2O (kg N/ha)**
Baseline	3,372	264	237	1.3
WF Residue Incorporation	3,372	288	231	1.5
NWF MD B	2,917	120	130	1.3
NWF MD A	2,660	112	68	1.6
NWF DS	3,220	181	212	0.9
WF MD A	2,657	165	63	1.6
WF MD B	2,915	178	121	1.4
NWF Res Incorporation	3,373	229	246	1.0

NWF Res Surface	3,373	243	326	1.0
NWF Straw Removal	3,371	179	-303	1.0
WF DS	3,222	248	193	1.3
WF Straw Removal	3,370	204	-275	1.5
WF Res Surface	3,372	305	282	1.5

Table 3. Summary model results for management in units of CO_2eq.

	CH_4 (t CO_2eq/acre)	**Soil C Gains (t CO_2eq/acre)**	**N_2O (t CO_2eq/acre)**	**Net GHGs* (t CO_2eq/acre)**
Baseline	3.00	0.35	0.26	2.90
NWF MD B	1.36	0.19	0.26	1.43
NWF MD A	1.27	0.10	0.32	1.49
NWF DS	2.06	0.31	0.17	1.91
WF MD A	1.88	0.09	0.32	2.10
WF MD B	2.02	0.18	0.27	2.11
NWF Res Incorporation	2.60	0.36	0.20	2.43
NWF Res Surface	2.76	0.48	0.20	2.48
NWF Straw Removal	2.03	-0.45	0.19	2.67
WF DS	2.81	0.29	0.25	2.77
WF Straw Removal	2.31	-0.41	0.30	3.02
WF Residue Incorporation	3.26	0.34	0.30	3.22
WF Res Surface	3.45	0.42	0.30	3.33

* The Net GHGs are the sum of the CH_4, N_2O and soil carbon. Note that soil carbon changes are listed as soil C gains, so positive numbers represent carbon sequestration.

GHG Emissions from Rice Straw Burning

Burning of rice crop residues results in a complex mix of aerosols and GHG emissions to the atmosphere that include PM, CH_4, CO, NO_x, and N_2O (Guoliang et al. 2007; Gupta et al. 2004; and others). DNDC is a soil biogeochemical model and does not quantify direct emissions from burning crop residues. Techniques for calculating emissions from residue burning on field crops (including rice, wheat, sugarcane, barley, corn, soybeans, and peanuts) are discussed in EPA (2007) and are based on the *Revised 1996 IPCC Guidelines*. Emissions are calculated using a series of step calculations and crop-specific statistics. Specific data needed for determining emissions by burning rice residues include annual crop production (derived from DNDC modeling), residue/crop ratio, dry matter content of the residue (%), crop burn efficiency (%), carbon and nitrogen content of the residue to be burned (kg of C or N / kg of dry matter), methane emission ratio (% CH4 emitted from C burned) and nitrous oxide emission ratio (%N_2O emitted from total N burned). We used EPA (2007) estimates of burn efficiency (93%), methane emission ratio (0.5%) and nitrous oxide emission ratio (0.7%). C and N fractions of residue was derived using DNDC modeled crop growth and shoot C/N ratio for each management scenario.

We assume that 97% of the crop residue is burned once every 8 years for pest management. Table 4 presents our estimates of methane and nitrous oxide emissions from burning of rice residues. Given the burn frequency is once over 8 years, the annual contribution on burning rice residues is ~0.1 tCO_2eq/ha, which is a small contribution to the total emissions from the fields for all management scenarios.

Table 4. GHG emissions from burning rice residues

	Residue C (kg C/ha)	Residue N (kg N/ha)	CH_4 (kg C/ha)	N_2O (kg N/ha)	Net GWP (t CO_2eq/ha)
Baseline	4,308	66	20.0	0.4	0.87
WF Residue Incorp	4,308	66	20.0	0.4	0.87
NWF MD B	3,727	57	17.3	0.4	0.75
NWF MD A	3,399	52	15.8	0.3	0.69
NWF DS	4,114	63	19.1	0.4	0.83
WF MD A	3,395	52	15.8	0.3	0.68
WF MD B	3,724	57	17.3	0.4	0.75
NWF Res Incorp	4,309	66	20.0	0.4	0.87
NWF Res Surface	4,309	66	20.0	0.4	0.87
NWF Straw Removal	4,307	66	20.0	0.4	0.87
WF DS	4,116	63	19.1	0.4	0.83
WF Straw Removal	4,306	66	20.0	0.4	0.87
WF Res Surface	4,308	66	20.0	0.4	0.87

Economic review summary

Cloe Garnache, John Thomas Rosen-Molina and Daniel A. Sumner at the University of California Agricultural Issues Center conducted the economic analysis for this project. The complete paper can be found in Appendix B. Below are summarized findings of their report concerning the yields, cost, and profit implication of modeled scenarios, and the impact of an emissions reductions market on potential profits.

The following scenarios do not attempt to reflect the actual proportions of California rice acreage. For example, only a few acres are drill seeded, almost none uses mid-season drainage and about 7 percent is baled[8]. The scenarios are hypothetical cases used to compare costs based on practices. Eight scenarios were analyzed, including the baseline; five modeled scenarios were not included due to scarcity of practice and very low probability of adoption (see Table 5).

Table 5. Rice management scenarios modeled with DNDC and included in economic analysis

Practice	Description	Scenarios for Economic Analysis
NWF DS	**No winter flooding with drill seeding followed by flooding 26 days after seeding**	**Not analyzed**

[8] Personal Communication. Paul Buttner, California Rice Commission. 2011.

NWF MD A	**No winter flooding with midseason drainage for 14 days starting at 35 DAS**	**Not analyzed**
NWF MD B	**No winter flooding with midseason drainage for 14 days starting a 45 days after seeding (DAS)**	**Not analyzed**
NWF Surface	**No winter flooding with residue mulched on surface following harvest**	**Not analyzed**
WF Surface	**Winter flooding with residue mulched on surface following harvest**	**Not analyzed**
Baseline	**Combination of the WF Residue Incorporation (60%) and NWF Residue Incorporation (40%)**	**Baseline Scenario**
WF Res Incorporation	**Winter flooding with residue incorporation**	**Scenario 1**
NWF Res Incorporation	**No winter flooding with residue incorporation**	**Scenario 2**
NWF Straw Removal*	**No winter flooding with residue removal**	**Scenario 3**
WF Straw Removal*	**Winter flooding with residue removal**	**Scenario 4**
WF DS	**Winter flooding with drill seeding followed by flooding 26 days after seeding**	**Scenario 5**
WF MD A	**Winter with midseason drainage for 14 days starting at 35 DAS**	**Scenario 6**
WF MD B	**Winter flooding with midseason drainage for 14 days starting a 45 days after seeding (DAS)**	**Scenario 7**

*Straw Removal may also be referred to as "baling" in the text.

Without a carbon market, profits per cwt (hundred weight, equivalent to 100 pounds) are highest for scenario 1 at $2.44 per cwt (see Table 6). Profits per cwt are $2.43 for the baseline scenario and $2.42 for scenario 2. Due to higher production costs from straw removal, profits are significantly lower for scenarios 3 and 4, $1.95 and $1.88 respectively[9]. Profits per cwt are $2.08 for scenario 5, which has a lower yield than the baseline but also lower costs per acre. Scenario 6 ($-3.91) and scenario 7 ($-1.39) have negative revenue per cwt due to lower yields.

Results from the DNDC model are shown in Table 6 and indicate that scenarios 2 through 7 would offer reductions in greenhouse gas emissions compared to the baseline. On a per acre basis, scenario 6 and 7 have the lowest emissions at 2.14 tCO2eq, followed by scenario 3 at 2.73 tCO2eq. When emissions from fuel use are added, the relative ranking of scenarios by emissions does not change.

[9] This analysis also requires a forced model assumption that none of the baled straw is sold and used, which would have the effect of reducing the growers' net baling costs from the assumed $50/acre level. This is a scenario that is not realistic in practice for a couple of reasons. First, without straw markets, baling is more expensive than soil incorporation. This is why current rate of baling is averaging about 7 percent, as this essentially represents the current amount of cost-effective alternative uses of straw. The remaining rice acreage is either incorporated or burned.

Table 6: Costs, yields, profits and average emissions for baseline and seven scenarios

Scenario	Total costs (1)	Model yield (2)	Model revenues minus costs (3)	Average GHG emissions per acre without fossil fuel emissions (4)	Average GHG emissions per cwt without fossil fuel emissions (5)	Avg. total GHG emissions per acre (6)	Avg. total GHG emissions per cwt (7)
	($/acre)	(cwt/acre)	($/cwt)	(tCO2eq/acre)	(tCO2eq/cwt)	(tCO_2eq/acre)	(tCO_2eq/cwt)
Scenario 0: Baseline	1572	87.79	2.43	3.13	0.036	3.45	0.039
Scenario 1: RI-WF	1570	87.71	2.44	3.31	0.038	3.62	0.041
Scenario 2: RI-NWF	1575	87.90	2.42	2.86	0.033	3.19	0.036
Scenario 3: Straw Removal-NWF	1616	87.88	1.95	2.73	0.031	3.00	0.034
Scenario 4: Straw Removal-WF	1622	87.88	1.88	3.07	0.035	3.34	0.038
Scenario 5: Drill-seeding; RI-WF	1542	84.44	2.08	2.88	0.034	3.20	0.038
Scenario 6: Mid-season drainage 30-42 DAP; RI-WF, MD A	1563	64.47	-3.91	2.14	0.033	2.44	0.038
Scenario 7: Mid-season drainage 40-54 DAP; RI-WF, MD B	1563	71.93	-1.39	2.14	0.030	2.44	0.034

Combined Tables 3a and 3b from the UC Davis report in Appendix B. **Note**: Emissions listed in column (4) differ from that of Table 3 in the Technical Summary of the CIG Final Report because these numbers only reflect averaged data from rice fields in the rice-producing counties in the Sacramento Valley. Table 3 of the Technical Summary averaged all fields in California, including some fields that had very low yields or that had wild rice varieties.
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.); (6) and (7) include GHG emission from fossil fuel use

However, ranking of scenarios by emissions changes when yields are considered, and emissions are calculated on a per cwt basis. Results from the DNDC model indicate that scenarios 2, 3, 6 and 7 offer the greatest mitigation potential, and that scenarios 2 and 3 are selected as the most likely to be adopted by growers under a carbon market. The mid-season drainage scenarios (6 and 7) offer significant GHG emissions reductions, but costly yield reductions likely due to water stress to the plants mean that payments for abatement will need to be very high, and similar reductions can be achieved for far less with scenarios 2 and 3.

Of the two scenarios that are most likely to be adopted, scenario 2 offers the greatest potential for GHG emissions reductions. Scenario 2 can achieve similar reductions to scenario 3 at lower cost. Practices under scenario 2 release about 0.26 tCO2eq less per acre or 0.003 tCO2eq less per cwt than the baseline, and profits are similar to the baseline. Emissions under scenario 3 are about 0.45 tCO2eq per acre or 0.005 tCO2eq per cwt lower than in the baseline, but profits are about 20 percent lower. It should also be noted that emissions in scenario 3 are likely to be understated because off-field decomposition/disposal of rice straw is not considered.

Profits were analyzed for scenarios 2 and 3 under a range of market prices for an offset credit for a ton of CO2eq. The range of market prices goes from $0 to $100 per ton CO2eq. Profits between the baseline and scenario 2 reach a breakeven point when the price for abatement credits reaches about $3.67 per tCO2eq. Above this price, net change in rice production and acreage will turn positive as growers switch to the practices described in scenario 2 because the revenue they receive for abatement will more than offset the additional costs of scenario 2. The breakeven point for scenario 3 is $92.90 per tCO2eq. This breakeven point is much higher than that for scenario 2 because per cwt profits for scenario 3 are significantly below the baseline. Overall, rice becomes more profitable relative to other crops under scenarios 2 and 3 with the availability of a market to sell carbon credits.

As the price of abatement credits rise, rice production and acreage increase linearly because growers start expanding rice land—over other agricultural land in the Sacramento Valley— as it becomes more profitable to produce rice under scenarios 2 and 3 and sell carbon credits. Further increases in the price of carbon credits will lead to net positive emissions because increases in rice production (spurred by higher profits from carbon offset credits) will outweigh the emissions reductions from mitigation practices. More detailed information about changes in rice production, land use, and net GHG emissions from different offset credit market prices can be found in Tables 4 through 8 in Appendix B, including projected changes using a different per cwt price for rice (2009 U.S. average $18.60 vs. hypothetical $8). While the shift in price of rice per cwt does change breakeven points, it does not change the relative profitability, acreage, rice production, and GHG emissions between scenarios and baselines.

Figure 3 depicts the ratio of profits to GHG emissions for each scenario. Scenarios 2 and 3 have higher values than the baseline. However, scenario 2 has the highest value, indicating that this set of practices maximizes the reduction in greenhouse gas emissions for the smallest change in producer profits.

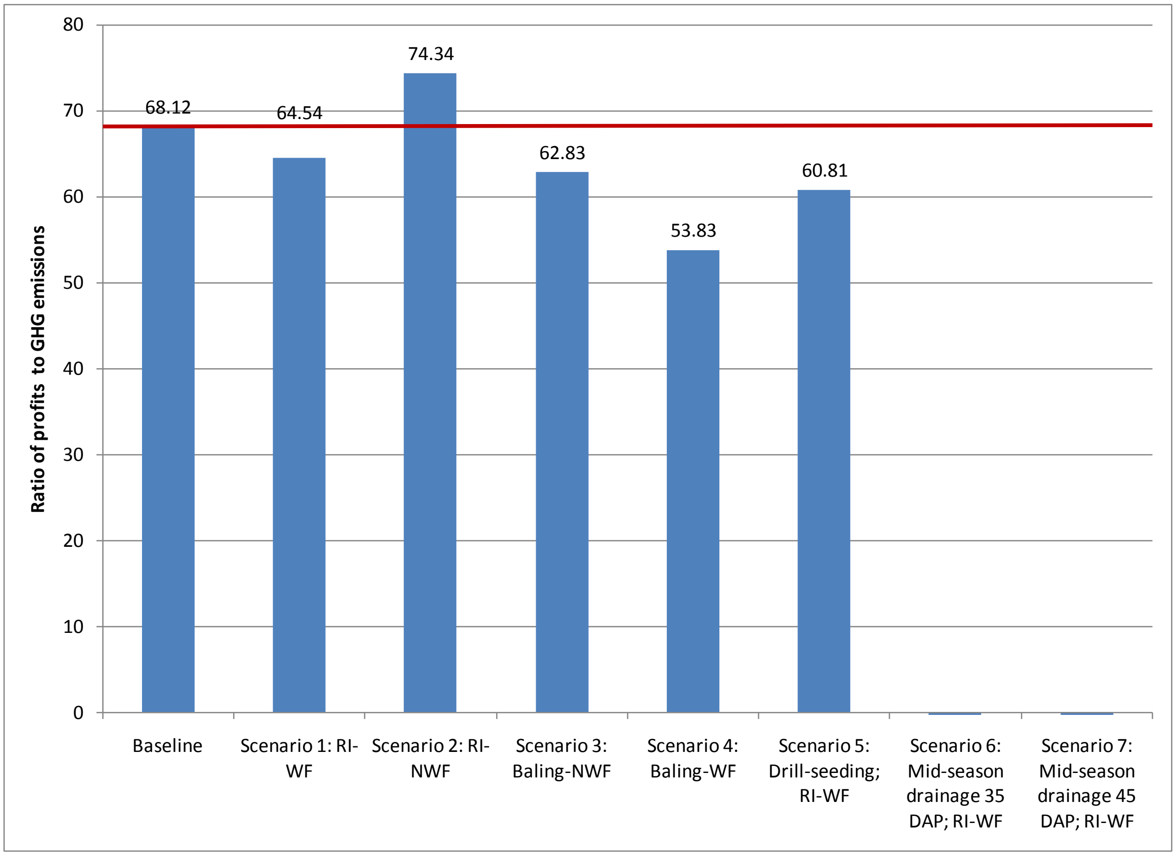

Figure 3. Calculated operating profits per ton of CO2eq emissions, by scenario
Source: Authors' calculations

Voluntary adoption of scenario 2 by the rice industry has already taken place in California. More widespread adoption is 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.

The analysis presented here assumes a hypothetical farmer in the Sacramento Valley, whose production practices are a representative sample of those employed throughout the state. One should bear in mind that actual costs and revenues are heterogeneous across farmers in the California rice industry. Furthermore, additional factors related to farm revenue from duck clubs, aggregation costs, registry fees, and verification costs have not been addressed, so operating profits do not directly equate to what farmers are expected to receive. Therefore, for farmers who have not already adopted the practices outlined in scenario 2, adoption will likely occur over a protracted period and may take place intermittently. Rice growers with the highest relative returns for scenario 2 compared to the baseline will be the first to adopt the practices in scenario 2.

Practice benefits and tradeoffs

Aside from the GHG benefits of the innovative practices mentioned previously, there are additional environmental co-benefits and tradeoffs in California.

Mid season drainage

Environmental co-benefits: In general terms, the fate of water applied to a crop is the sum of evaporation, plant transpiration, percolation, and run-off (surface water exiting the field). Assuming no compromise in productivity, transpiration will be comparable between the two irrigation strategies. Percolation and run-off are not considered water-use because that water remains in the hydrologic basin either as ground water or surface water. Therefore any water savings from mid-season drainage could be attributed to less evaporative loss from the field under drained conditions, such savings would be considerably less than the difference in water applied. More study is required to sufficiently address the open question of whether measureable water savings actually occurs from the use of this practice[10]. The value of reducing application to the fields may be that the water remains in the river channel and perhaps would be a greater benefit to environmental concerns.

Environmental tradeoffs: The practice of mid-season drainage needs further testing in California, as field trials led to a slight decline in yield and delayed plant development based on preliminary studies. For offset crediting purposes, this decline in yield could lead to leakage issues because new rice production elsewhere would attempt to compensate for yield decreases while producing new environmental effects.

Straw management:

Straw incorporation:

Environmental co-benefits: Benefits include increased soil organic matter, recovery of about 25 lb/acre of nitrogen in the straw, improved waterfowl habitat due to winter flooding, and improved air quality due lack of burning.

Environmental tradeoffs: Straw incorporation also led to an increase in fungal disease inoculum in the soil, additional production costs, loss of upland game bird habitat, saturated soils provide less of buffer for flooding, and increased water use. Whether or not straw incorporation increases the concentration of dissolved organic matter (DOM) in surface is under study. The Regional Water Quality Board lists DOM as a constituent of concern.

Straw removal:

Environmental co-benefits: Because straw does not need to decompose in the field, there is no need for winter flooding, which would produce water savings. However, if waterfowl habitat were the intent, straw could be removed and the fields could be flooded. Straw removal also allows for faster drying of the soil in the spring so that field preparation can begin earlier. The economic benefit of selling rice straw is presently the exception.

Environmental tradeoffs: Winter flooding provides forage opportunities and habitat for millions of waterfowl moving along the Pacific Flyway. It has been an important factor in the recovery of waterfowl populations in California. Furthermore, about 57% of

[10] Personal Communication. Paul Buttner, California Rice Commission. 2011.

Sacrament Valley wetlands rely on tailwater from rice fields. A new source of water at an additional economic cost would have to be identified.

Drill seeding:

Environmental co-benefits: Less water diverted from the rivers during May can be beneficial to fish and riparian habitat, but overall water savings are not well documented[11].

Environmental tradeoffs: Any known tradeoffs have not been identified.

DEVELOPMENT OF METHODOLOGY

The purpose of the methodology is to accurately quantify GHG reductions (CH4 and N2O) and develop offset credits that are real, additional, verifiable, enforceable, and permanent. The methodology is being written for an aggregated project and currently includes three practices that have met a certain level of DNDC accuracy: reducing winter flood, straw removal after harvest, and drill seeding. However, the methodology can also be appropriately revised to include additional practices after sufficient verification has been conducted.

The project area for the methodology will be located in an area for which DNDC has been successfully calibrated for each of the proposed project activities implemented using empirical gas flux data on at least five individual rice fields, or at least 1,000 acres. This would reduce structural uncertainty related to model predictions. Requirements for eligibility also include lands that have been farmed five years preceding the crediting period, with at least four months of flooded fields during the growing season. Climate data and management records must also be available to determine baselines. Project activities must not lead to statistically significant rice yields in order to prevent leakage.

This methodology allows for grouped projects with the option for new project areas to be added to an existing project after the start of the crediting period. In fact, a large number of fields (with homogenous conditions) spread out over a geographic region within one project is encouraged to reduce costs. Otherwise, parameters such as common rice cultivation practices, biophysical conditions, landscape type, costs and returns of rice cultivation, and any legally binding requirements affecting the project need to be accounted for.

POTENTIAL FOR TRANSFERABILITY OF RESULTS / NEXT STEPS

The results of this project, primarily the development of a GHG methodology for rice, can be transferable in two respects. As it is being developed, the methodology offers the potential to include other management practices as well as those in other regions through revisions to the protocol. In order to include more practices, the methodology requires further verification of DNDC of the respective practices, such as mid-season drainage, which would encompass additional data collection at trial sites. Further specification as to what calibration is needed will

[11] Some work by Linquist and Snyder, UCD, found little difference in the water used in a flooded vs. a drilled system.

be provided. Additionally, other rice producers will be able to participate in GHG projects and access carbon markets through this methodology, and this project may also be used as a guide for other agriculture commodities in California more broadly.

After the methodology is finalized, we plan to submit it to two carbon registries, Voluntary Carbon Standard and American Carbon Registry, to undergo third-party verification and protocol development. Furthermore, a proposal based on this project would implement pilot projects in California and Arkansas using the methodology in order to demonstrate the opportunities to generate offset credits for trading (replication potential research for other rice-growing states will also be conducted). These opportunities are expected to be available by the next planting season (mid-2011), and continued outreach to rice producers to explain the protocols will help identify willing participants to launch pilot projects. Adoption of a protocol by the California Air Resources Board would allow rice offset credits to be used in the compliance market.

Lastly, several papers related the use of the DNDC model and the economic analysis of the project will be submitted for peer review in the near future.

CONCLUSION

The project has demonstrated DNDC model performance for rice farms in California and has defined future research and outreach needs to establish a functioning offset credit protocol that is environmentally and economically attractive for credit buyers and rice producers. Through expert consultation, modeling of existing management practices and field trials, we have helped inform the emissions baselines and likely results of changes in practices, as well as the feasibility of practice adoption by growers. The economic evaluation is the foundation for understanding the effect of practice changes on farm revenue and potential revenue from a carbon market. However further economic considerations can be accounted for with greater understanding of carbon market transaction costs. The analysis of co-benefits and environmental tradeoffs also provide key considerations when implementing practice changes. Further research is needed to test for unintended environmental consequences in order to help rank practice costs and benefits.

Protocol developers have a more informed idea of which rice management practices will contribute to real GHG reductions and which ones will be economically feasible to put forth in a carbon market. Conducting pilot projects and testing user experience (either the grower or an aggregator) of the DNDC model will further validate the functionality of an emissions reduction program in the Sacramento Valley by illustrating its effectiveness across the heterogeneity of practices and costs/revenues of production systems that were not able to be accounted for in the model runs. Analyzing user experience will also help to project realistic grower acceptance of an emissions reduction program.

The development of a high standard protocol using rigorous science-based models to account for GHG reductions will help to include rice growers in the creation of carbon offset credits. Further validation of the DNDC model for other management practices not addressed in the methodology could increase the number of mitigation options. As a whole, the results of this project provide a framework for future carbon projects involving rice growers, and an example to other crop producers in California, as well as across the United States, who wish to expand their GHG emission reductions opportunities.

APPENDIX A: EXPERT ADVISORS TO THE PROJECT

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APPENDIX B: UC DAVIS ECONOMIC REPORT

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

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1. Project Background

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.

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 program, 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 statement.

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. 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_20) 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_20 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

The following scenarios do not attempt to reflect the actual proportions of California rice acreage. For example, only a few acres are drill seeded, almost none uses mid-season drainage and about 7 percent is baled (Buttner, 2011). The scenarios are hypothetical cases used to compare costs based on practices.

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 predominant 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. In line with the UCCE study and the DNDC model results, we use a weighted average for straw management with 13 percent of acreage burned, 60 percent winter flooded and incorporated and 27 percent incorporated without winter flooding. 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 applied 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. For the cost calculation we assume that water is purchased for 60 percent of the acreage. On 27 percent of the acreage rice straw is rolled with a cage roller and on 60 percent of the acreage the farmer undertakes a chop and disc operation.

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 from 50 lbs/acre to 100 lbs/acre (Mutters 2009.)

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). However, we add a $50 custom rent per acre for baling and bale removal (Mutters 2009.) As with all other operations and scenarios, choice to bale and net costs vary by farm situation across the valley. Moreover, as with all other scenarios, costs and GHG implication of any off farm activities are not considered.

There is no winter flooding, so purchased 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 (Mutters 2009.)

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 for baling and bale removal (Mutters 2009.) As with all other operations and scenarios, choice to bale and net costs vary by farm situation across the valley. Moreover, as with all other scenarios, costs and GHG implication of any off farm activities are not considered.

Like in the baseline scenario, we set purchased 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. For cost calculations, we assume $6 per acre in water purchase costs is saved relative to the baseline. Little experimental evidence is yet available to determine precise savings in evaporation, but the effect is expected to be quite small (Mutters 2009 and Buttner 2011.)

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. Purchased 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. For cost calculations, we assume $6 per acre in water purchase costs is saved relative to the baseline. Little experimental evidence is yet available to determine precise savings in evaporation, but the effect is expected to be quite small (Mutters 2009 and Buttner 2011.)

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. Purchased 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, have estimated production costs of $1563 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 $24.24 per cwt, while scenario 7 has costs of $21.73 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 net revenue per cwt due to lower yields.

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_2eq. 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_2eq, 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_2eq. 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 about $3199 while scenario 7 would have a breakeven price of about $649. 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. 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 alternative scenarios.

Six of these alternative scenarios have greenhouse gas mitigation potential compared to the baseline. Out of these, 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. However 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. 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 differences in costs or yields across fields and farms of different characteristics. 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 issues 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
			(acres)			
Total planted	135,090	198,989	97,169	51,783	11,599	**494,631**
			(acres)			
Flooded	75,760	60,247	38,459	16,368	3,699	**194,534**
			(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

Panel A Source: Mutters et al. 2007 and updated using California County Agricultural Commissioners' Data, 2008. United States Department of Agriculture, National Agricultural Statistics Service, California Field Office.
Panel B. Source: Salas 2010.

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

Scenario	Total costs (1)	Model yield (2)	Model revenues minus costs (3)	Average GHG emissions per acre without fossil fuel emissions (4)	Average GHG emissions per cwt without fossil fuel emissions (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	1563	64.47	-3.91	2.14	0.033
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	1563	71.93	-1.39	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 $8/cwt price for rice	
	Breakeven price	Reduction in GHG compared to baseline	Breakeven price	Reduction in GHG compared to baseline
	($/t$CO_2$eq)	(percent)	($/t$CO_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	4457.26	-29.22	3198.78	-29.22
Scenario 7: Mid-season drainage 45 DAP; RI-WF, MD B	717.65	-29.17	648.46	-29.17

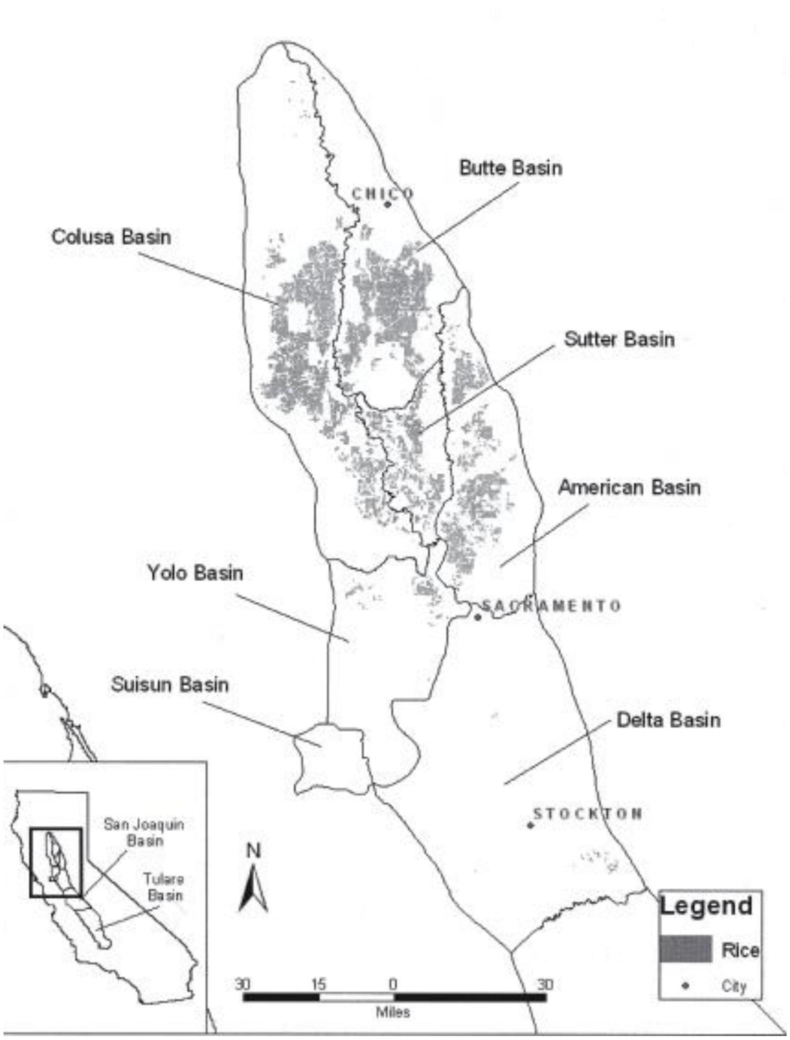
Sources: Authors' calculations from Table 3a and hypothetical $8/cwt price and costs from 2007 UCCE study

[1] The market price of $18.6/cwt is from NASS 2010.

[2] From Table 3a

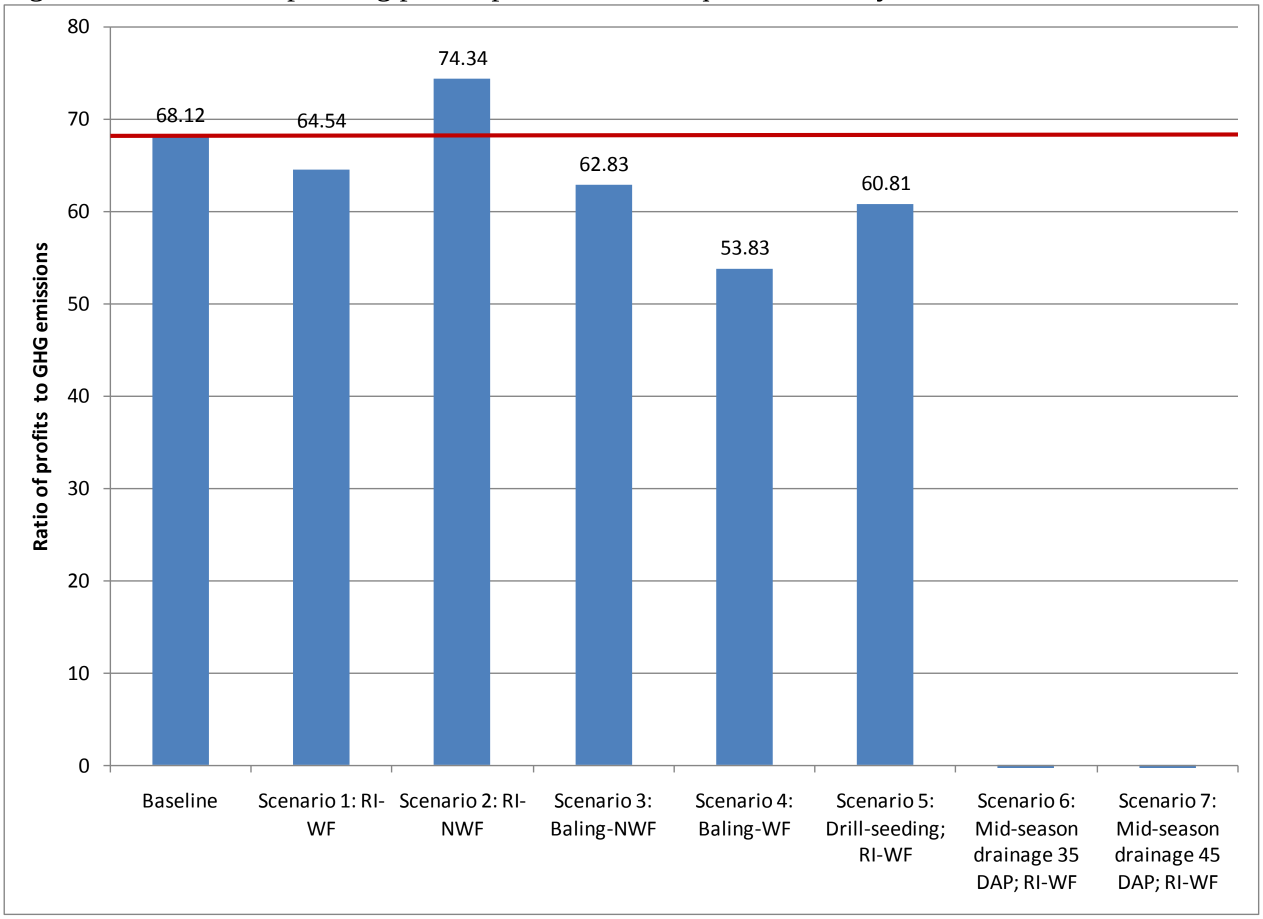
[3] From UCCE cost study cited.

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.