Rice in the Delta – The Potential to Mitigate Subsidence and Enhance Sustainability

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Subsidence threatens Sacramento – San Joaquin Delta sustainability, with implications on the Delta agricultural culture and viability, on the economies of the Delta and other California regions, and on security of California's water conveyance infrastructure. Rice potentially offers a viable agricultural alternative that is a regional solution for subsidence through its effect on peat biogeochemistry and on resulting oxidation rates. Reviewing agronomic, GHG emission and direct measurement data shows subsidence rates under rice essentially stop as compared to other cropping types. Strategic placement of rice throughout the Delta could stabilize levees and the risks to California's water supply. Current hypotheses that strategic rice placement on islands can decrease levee failure risks are being tested using standard tools for assessing Delta levee stability. For a significant impact, large-scale implementation of rice in the Delta would be needed. Transitioning to a Delta crop mosaic with a critical mass of rice needed to meaningfully address subsidence risks will result in a broad range of effects including agricultural, water quality, water hydrology, greenhouse gas emissions, and carbon cycling. The AFRI (Agriculture Food and Research Initiative) Rice project is a $5M National Institute of Food and Agriculture (NIFA) Climate Change and Water Resources grant funded project. Under the AFRI Rice project, peer reviewed findings to lab-scale studies to regional-scale assessments are being integrated to understand and prioritize the key drivers behind the different effects. These findings are being integrated into a regional Delta assessment and into the Delta Agricultural Production (DAP) and other economic tools to quantify local, regional and statewide economic costs and benefits. The project will provide an economic and mechanistic based framework for future land use decisions in the Delta with the goal of creating a more sustainable and beneficial future for the Delta and to improve water security for California.

Keywords: GHG, Subsidence, Levees, Hydrology, Water quality, economics, water security
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Session Time: Wednesday 10:20AM – 12:00PM Room 308-310

The Influence of Soil Total Carbon on Yield and Nitrogen Uptake in Continuously Flooded Rice Paddy Soils Dominated by Peat

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Agriculture on peat soils has a well-documented negative impact on peat subsidence, leading to undesired environmental consequences. Rice cultivation shows potential to enable peat soils to remain agriculturally productive while reducing these environmental impacts. However, peat soils have unique fertility requirements that must be better understood for rice cultivation to be successful. Specifically, this study sought to quantify the amount of nitrogen supplied to a rice crop from peat mineralization across a wide range of soil organic carbon (SOC). A total of ten nitrogen rate trials over three seasons were established over a range of SOC from 2.5% to 23% in the Sacramento-San Joaquin Delta. Nitrogen fertilizer rates of 0, 40, 80, 120, and 160 kg N/ha were applied in each trial in a RCBD with four replicates. Additionally, 30 nitrogen-omission plots were established in 2013 to observe yield response outside of the rate trials across the range of SOC. Yield response to nitrogen application was greatest in the 2.5% and 23% SOC trials, with little to no yield response in the intermediate range of 10-15%. The nitrogen-omission plots mirrored this trend, with the greatest yields observed in the 10-15% SOC range and with lower nitrogen-omitted yields occurring in the 2.5% and the >23% SOC range. Aboveground nitrogen uptake was modeled as a function of SOC, showing the SOC range with maximum nitrogen uptake coincided with the SOC range with lowest observed yield response to added nitrogen. The estimated model coefficients agreed generally with previous work although greater background nitrogen variability was observed. These results suggest nitrogen fertilization of flooded peat soils may be unnecessary in certain ranges of SOC. Further study is needed to understand the mechanisms that result in the quantity of plant available nitrogen release from these soils during flooded conditions.

Keywords: rice, agriculture, peat soils, mineralization
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Interannual Variation in CO_2 and CH_4 Fluxes from a Rice Paddy in the Sacramento-San Joaquin Delta, California

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The Sacramento-San Joaquin Delta was drained over a century ago for agriculture and human settlement and has since experienced subsidence rates that are among the highest in the world. To help capture carbon and reverse subsidence and there is growing interest in converting drained agricultural land-use types to flooded ecosystems such as rice paddies. Rice has been shown to be a viable crop for slowing subsidence in the Delta as the flooded status of these ecosystems inhibits peat oxidation. However, while rice can help reverse net carbon loss and subsidence, flooding also increases the emission of methane (CH_4). We measured continuous fluxes of carbon dioxide (CO_2) and CH_4 over a rice paddy in the Delta from April 2009 through April 2014 using the eddy covariance method to document how CO_2 and CH_4 fluxes vary interannually and to examine how environmental and management factors influence annual CO_2 and CH_4 budgets.

While the rice paddy was consistently an atmospheric sink for CO_2, annual CO_2 budgets were highly variable between years; net CO_2 sequestration ranged from 537 g C m^{-2} yr^{-1} in 2010 to 70 g C m^{-2} yr^{-1} in 2013. There were also considerable differences in CH_4 budgets between years, with the rice paddy releasing between 2.5 to 6.6 g C m^{-2} yr^{-1} as CH_4 throughout the study. Year to year differences in CO_2 and CH_4 budgets were due in part to variations in weather, but were also strongly influenced by differences in management practices between years (e.g. the timing of flooding/draining and planting/harvesting, discing versus plowing, and herbicide and fertilizer treatments). The results of this study can be used improve management of rice agriculture to maximize carbon uptake and minimize CH_4 emissions, which is critical to halting subsidence in the Delta and reducing greenhouse gas emissions from the region.

Keywords: Rice, Carbon fluxes, Methane, Greenhouse gas, Management, Eddy covariance
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Hydrologic and Water Quality Effects of Varying Land- and Water-Management Strategies, Sacramento-San Joaquin Delta

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On Delta islands where organic soils predominate, ongoing subsidence results in increasing seepage, drainage volumes and drain-water constituent loads. To assess alternate land- and water-management strategies on Delta islands, we used hydrologic data and groundwater-flow and solute-transport modeling to answer questions about drainage-groundwater interactions, effects of drain-water DOC and salinity loads for business as usual and with alternate land- and water-management strategies. We considered various assemblages of cropping and land-use patterns that included rice and wetlands for carbon sequestration.

We determined hydraulic conductivity of island sediments, monitored groundwater levels, collected and analyzed ground- and drain-water samples, and measured drain flow. We used these data to construct a groundwater flow model for Twitchell Island. For the solute transport model, we developed dispersivity and diffusion coefficient values from laboratory experiments and the literature. We used the models to simulate different cropping and water-management practices. We simulated land-surface elevation changes using previously published subsidence and accretion models. Island groundwater levels and drainage volumes are influenced by varying recharge, channel water levels, and seepage through levees. Drainage loads are determined primarily drain flow and secondarily by mobilization of solutes from soil to groundwater and drain water.

Model results agreed well with measured water levels, drain flows, and DOC loads and concentrations. Under the business as usual scenario, continuing subsidence and sea level rise lead to increases in drainage DOC loads by about 20% by 2050. Model results also indicate that subsidence mitigation measures such as rice and wetlands can reduce organic-soil oxidation will reduce seepage, drain flow, and drain DOC loads, relative to business as usual.

Keywords: subsidence, water quality, sustainability, levees
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Expanding Rice Farming in the Delta: Significance for GHG, Water Supply Reliability and Water Quality

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Conversion of selected areas in the Delta to rice farming has the potential to reduce net greenhouse gases (GHGs), improve Delta water quality, support through-Delta water conveyance, and support flood-protection of subsided lands. These outcomes achieve major policy goals of the State of California as set by AB32, the Porter-Cologne Water Quality and Clean Water acts, and the Delta Reform Act. Through the AFRI Delta Rice Project, our team is identifying feasible agronomic approaches to rice production in the subsided Delta that reduce net GHG production, halt ongoing land subsidence, improve levee stability, and reduce DOC and nutrient loading to Delta waters. We present a framework that uses the team's findings on the effects of rice production in order to articulate when and where rice could be deployed, and to what net gain. Now ending its third year, the AFRI team has identified the primary factors controlling GHG production, DOC and nutrient loading, subsidence rates, and levee stability associated with rice farming in the Delta. We combine these factors with spatial data on soils, topography, land management, and through-Delta conveyance to construct hypothetical models that use rice farming to optimize for each effect. With this framework, we will assess where conversion to rice production can enhance water conveyance security and protect Delta lands through reduced levee failure risk, and estimate the cumulative benefits to GHG emissions and Delta water quality. Results to-date indicate that conversion to rice production can offer demonstrable benefits across this range of societally valued outcomes. These findings feed directly into the economic assessment for the AFRI Delta Rice Project by helping to identify potential types and sources of subsidies suited to support rice where production alone does not cover all of the costs.

Keywords: Greenhouse gases, subsidence, conveyance, flood protection, water quality, regional scaling
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