ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2013-December 31, 2013

PROJECT TITLE: Improving fertilizer guidelines for California's changing rice climate.

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OBJECTIVES OF THE PROPOSED RESEARCH

Our overall objective of this project is to develop fertilizer guidelines for California rice growers which are economic viable and environmentally sound. Toward this objective, in 2011 the following specific objectives will be addressed.

1. Determine the potassium status of rice soils.
2. Quantify N losses due to NO_3 leaching in California rice systems.
3. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

EXPERIMENTAL PROCEDURE TO ACCOMPLISH OBJECTIVES:

OBJECTIVE 1: POTASSIUM STATUS OF RICE SOILS.

Background

Rice takes up from the soil about the same amount of potassium (K) as nitrogen (N) – roughly 150 lb/ac. However, at harvest about 80% of the K is in the straw and 20% in the grain; whereas for N about 20% is in the straw and 80% in the grain. Thus, with current straw management practices, in which straw is retained in the field, most of the K is conserved in the soil; however about 20-30 lb K/ac is removed in the grain each year. Given enough time, this continual removal (or mining) of K from the soil will eventually lead to K deficiencies unless K is replaced by the use of fertilizer or some other means. Due to the heavy clay soils which contain a lot of K reserves, K deficiencies have not been a large problem for most CA rice growers (the exception is the red soils on the eastern side of the valley), despite the fact that most growers do not apply K fertilizer. However, in recent years there seems to be an increasing number of fields that are showing signs of K deficiency. In addition, there is increasing talk about the use of rice straw for off-site purposes. Removal of rice straw will accelerate the mining of K from soil since much of the K is stored in the straw at harvest. The value of this K is information for growers considering removing straw from their fields.

Given this background, the objectives of this research will be to quantify the K status of soils around the Sacramento Valley and identify under what circumstances K deficiencies are likely to occur. The factors to be examined will be soil type, fertility management, inputs through irrigation water, and straw management.

Materials and Methods

In 2012 we identified 31 fields and in 2013 – 24 fields. From each field, soils samples were taken from the top, middle and bottom checks before any fertilizers were applied. These soils were analyzed for extractable K. Twice during the season water was sampled at the inlet and analyzed for K content. Near heading flag leaf samples were taken from plants within each check that the soils had been sampled. These leaf samples were also analyzed for K. In addition to these samples, each grower was interviewed as asked about historical (past 5 years) yields from fields, straw management and winter flooding practices. In 2013, we looked for fields where K had not been recently applied, or that were irrigated with well water, or were in locations not sampled in 2012.

Results

Data from this study is still being processed. We are combining the two years of data (2012 and 2013). The results presented here are summary in nature and summarize results from both years.

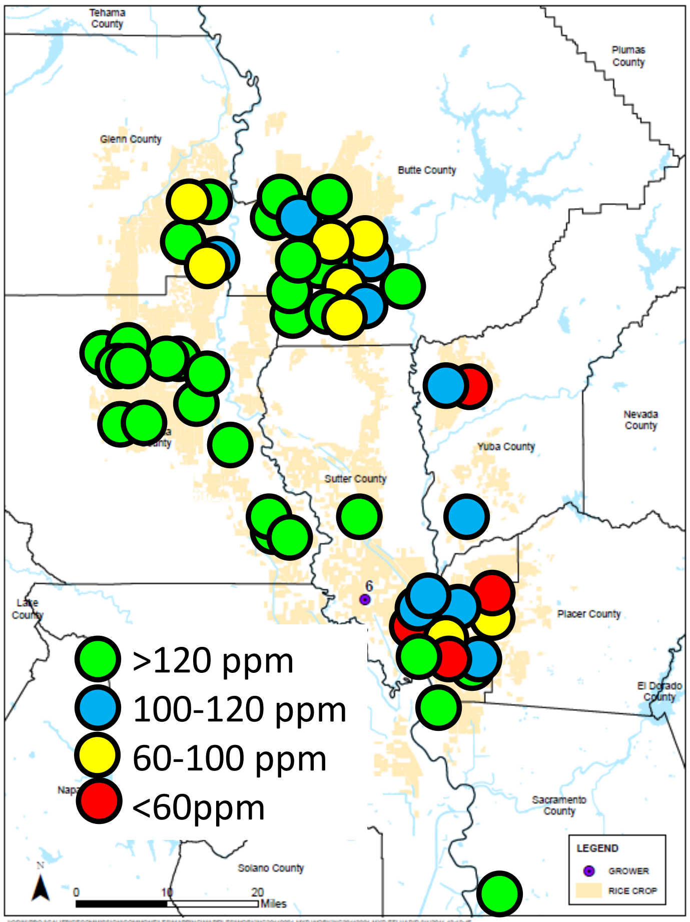


Figure 1. Approximate locations of 2012 and 2013 field studies and average soil K concentrations from each field.

Field histories

In 2012, 14 of the 31 fields that we investigated had a recent history of K application; while in 2013 6 of the 24 fields had recently received K fertilizer. The average application rate, based on fields where K was applied, was 33 lb K_2O/ac. Two fields (both in 2013) in our study had had straw bailed regularly. Eleven fields used well water for irrigation.

Variability between checks within a field

Data from previous experiments on K has shown that K does move readily in the water. Based on this we thought that K may accumulate in the lower checks near the outlet as it is "pushed" downward. Soil K did vary between checks, however, there was not a consistent pattern. However, we need to look at the data and fields more carefully in this regard as some of the fields had multiple inlets and outlets. These fields would need to be removed from this analysis.

Soil K values

Soil K values ranged widely among fields from as low as 35 ppm to as high as 350 ppm (the critical level is 60 ppm). There was no relationship between soil K values and the amount of K that had been added and removed (based on recent history data). The primary patterns we saw were:

1. Soil K values were lowest in the south-east, followed by north-east and north west. Highest values were in south-west (Fig. 1).

2. All fields below 60 ppm (critical value) were on the east side of the valley.

Soil K values and flag leaf K concentration

The critical flag-leaf K value is 1.2%. In this study 11 checks had K values below1.2%. When Soil K values were below the critical value of 60 ppm then ½ of the flag leaves sampled had K values below the critical range (Fig. 2). However, when soil K ranged from 60 to 120 ppm, 8 flag leaf samples had K levels below the critical range. This data suggest that K fertility may need to be considered at K levels below 120 ppm.

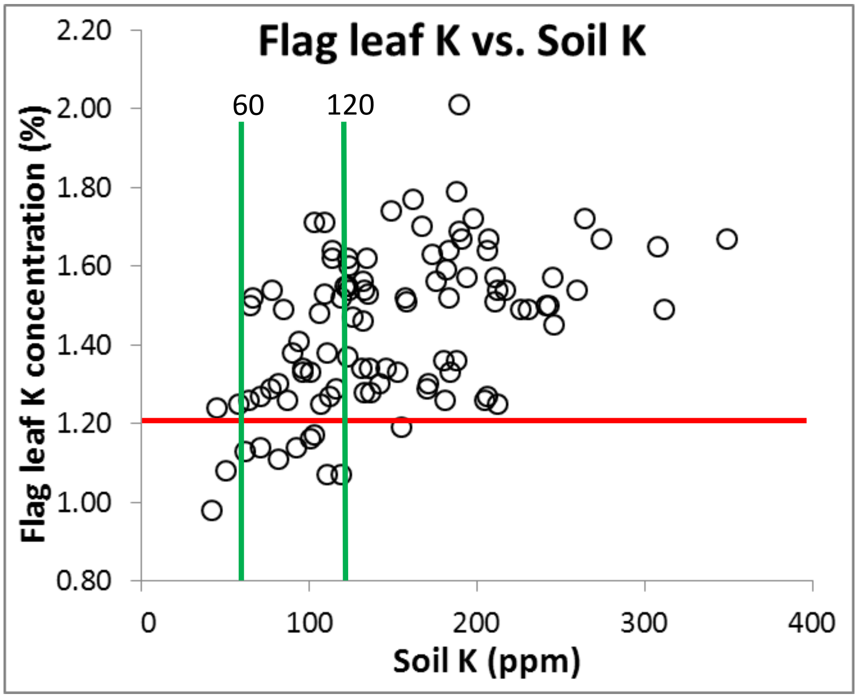


Figure 2. The relationship between soil K and flag leaf K values in 2012 and 2013 fields where K fertilizer was not applied.

K concentrations of irrigation water

There was a significant difference in the concentration of K in irrigation waters (Fig. 3). Of the two primary rivers, the Sacramento River had the highest K values (1.18 ppm) while the Feather river averaged 0.79 ppm. Well water had the highest overall K concentration (2.3 ppm) but it was also highly variable. Recycled irrigation water averaged 1.4 ppm and was also variable.

The west side of the valley is irrigated with Sacramento River water. This difference in irrigation water K concentrations may be one of the reasons (there are other reasons such as soil type) why soil K levels are higher on the west side of the valley.

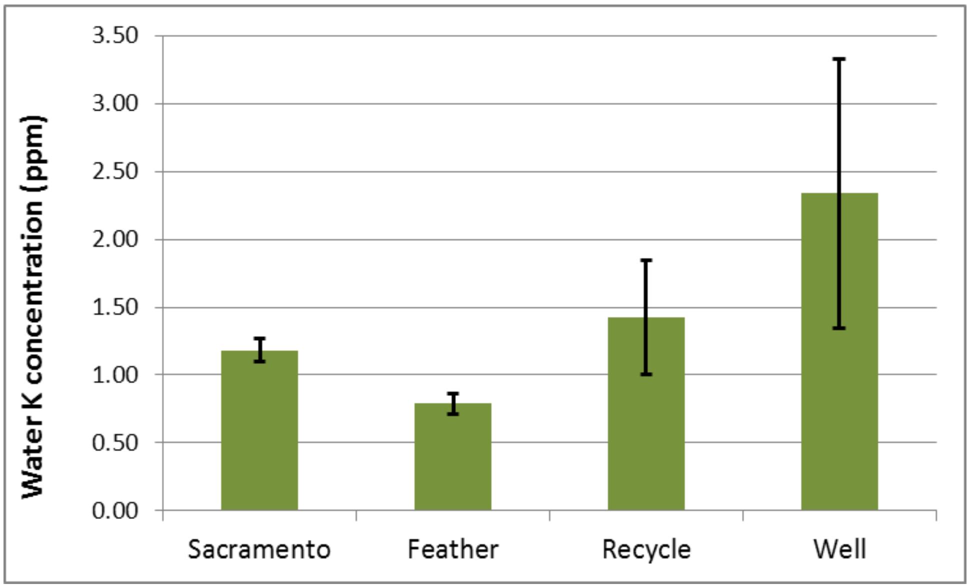


Figure 3. Average K concentration of irrigation water from various water sources. Feather river includes the Yuba and Bear Rivers.

<u>Future work</u>

Field research for this project is finished. In 2014, we will finalize our analysis of 2012 and 2013 research findings and develop K fertility guidelines for rice growers.

OBJECTIVE 2: QUANTIFY N LOSSES DUE TO NO_3 LEACHING IN CALIFORNIA RICE SYSTEMS

<u>Background</u>

The irrigated lands program may begin putting water quality restrictions on agricultural management practices that allow NO_3 to enter surface and ground waters. In a previous CALFED funded project we have addressed NO_3 in surface waters. This project is focusing on ground water and NO_3 leaching. There is very little data available that quantifies NO_3 leaching is flooded rice systems. Some studies from Asia have reported NO_3 leaching below the root zone in rice systems (Yoon et al., 2006 and Zhu et al., 2000); however the methodology employed in these studies may have caused this leaching. In another study, Bouman et al. (2002) reported potential leaching beneath rice fields but that it was minimal compared to other systems. In California, rice soil are relatively impermeable and it is thought that the potential for NO_3 leaching is minimal due to the slow percolation of water downward and the fact that the anaerobic conditions in flooded soils would cause the NO_3 to denitrify (lost to the atmosphere as gas) before it had a chance to leach beyond the rice rooting zone. While this is a good theory it has not been proven in the field. The objective of our study is to quantify NO_3 leaching losses in rice fields which will provide a basis upon which legislators can make sound decisions. To accomplish these objectives we:

1. Measured NO_3-N in soil samples to a depth of 7 feet (2m) (Fig. 1 for site locations).

2. Directly measured NO_3-N in water below the rice root zone for a full year at 4 locations.

3. Measured labeled fertilizer NO_3-N to determine source of below root zone NO_3-N.

4. Analyzed data from shallow wells in the rice growing region for NO_3-N.

Results

This research has been completed. This information has also been made available to various stakeholders including growers, the California Rice Commission, and legislators. It is important that this information is properly documented so research does not need to be repeated. Therefore, in early October research findings were submitted for publication in the Journal of Environmental Quality.

In this report, I will not go into the details of our findings but rather provide the abstract from the manuscript that was submitted (in **bold** is the key statement).

Abstract: Irrigated croplands can be a major source of nitrate (NO_3–N) in groundwater due to leaching. In California where high NO_3–N levels have been found, the contribution from rice systems has not been determined. The extent of NO_3–N leaching from rice systems was evaluated from: soil cores (0–2m) from eight fields over a four year period (Fig. 1); the fate of ^{15}N fertilizer in replicated micro-plots located in four fields; and regional wells. Soil NO_3–N concentrations were ≤ 3.3 mg kg^{-1} (usually <1 mg kg^{-1}) below the root zone (<33 cm). NO_3–N in pore water samples was only observed below the root zone during the first two weeks following the onset of flooding in either the growing season or winter fallow period and was always ≤8.4 mg L^{-1}. Fertilizer N accounted for 0 to 11.8% of NO_3–N in pore water samples below the root zone. After one year 2.5% of fertilizer N was recovered as ^{15}N below the root zone (33 – 100 cm). We hypothesize that this downward movement of fertilizer N was been due to NO_3–N leaching in permeable soils or via preferential flow through cracks in heavy clay soils. Based on a regional assessment, wells that are directly associated with rice all had median NO_2– and NO_3–N levels below 1 mg kg^{-1} (Fig. 1). **These results all indicate that NO_3–N leaching is not a concern for the majority of California rice soils under current crop management practices.**

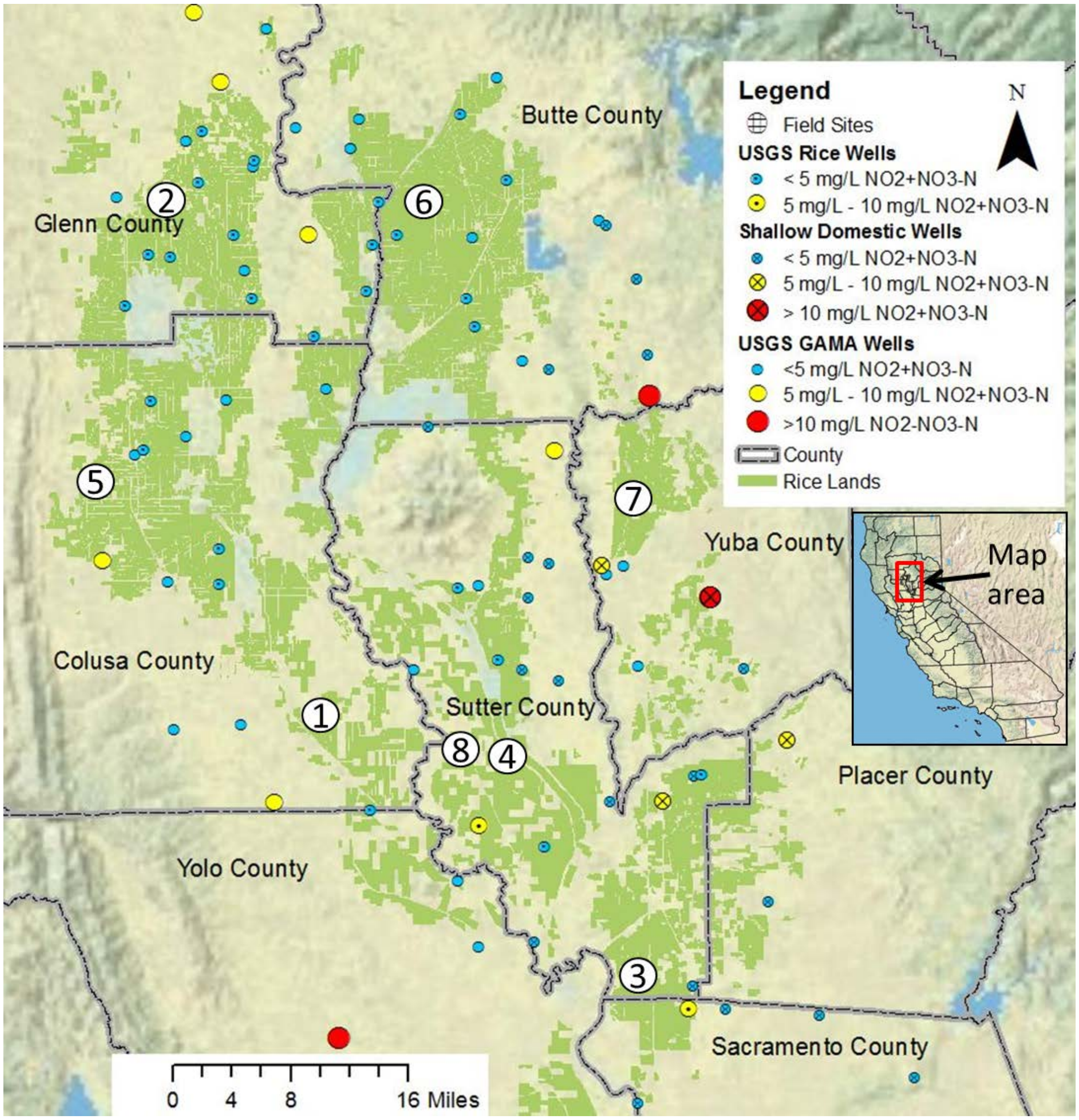


Figure 1. Map of the Sacramento Valley delineating rice production areas, location of field studies (see Table 1), locations and types of wells selected to assess groundwater NO_3–N impacts within and near rice lands and the maximum nitrite/NO_3–N concentrations in those wells during the observation period.

Future work

The results of this research have been submitted for publication. We will make sure this work sees it through to final publication.

OBJECTIVE 3. DEVELOP MANAGEMENT PRACTICES FOR GROWING RICE UNDER CONDITIONS OF ALTERNATE FLOODED/DRY SOIL CONDITIONS.

Background

Current water management for rice production in California is to keep the field continuously flooded. Such practices provide high yields, good weed control and N-use efficiency. Furthermore, recent research has shown that on the highly impermeable California rice soils water is used efficiently. For example, when we have compared drill seeding with wet seeding, the total amount of water used is similar - despite the fact that wet seeding requires the soil be flooded for almost a month longer than when rice is drill seeded. However, there is increasing concern (which may or may not be valid) that growing rice under continually flooded conditions can lead to other problems. Examples of this include high greenhouse gas emissions (especially methane), arsenic (As) uptake in rice, and methyl mercury production in anerobic flooded rice systems.

Research that has evaluated growing rice in CA under conditions where the soil alternates between wetting and drying (we will refer to this as alternate wet and dry –AWD) has shown that rice yields can be reduced substantially. Reasons for these yield reduction are not understood.

While we are not promoting the growth of rice under alternate wetting and drying conditions it is important for the rice industry to be prepared for scenarios whereby there may be increased pressure to grow rice under such conditions. Our objective for this research is to develop AWD management practices that are the most economically viable for California and compare them to conventionally flooded rice. This research will demonstrate whether or not an AWD system is viable and if not, will provide the data for an economic analysis of what are the additional costs of using AWD production systems to mitigate environmental concerns.

Methods

In the summer of 2012, a research site was established to evaluate three different water management practices each replicated three times:

1. Water-seeded conventional
2. Water seeded with flood maintained till canopy closure – then flush irrigated
3. Drill seeded with continuous flushing.

These treatments were determined based on previous experience. The plots are large (greater than 0.5 ac) and will be adequate for various other measurements and treatments. Within each plot a soil moisture probe was put in place to constantly measure soil moisture content. Reflooding was always done when the soil moisture reached 35% water by volume.

Nitrogen management for these systems will likely be different due to different water management strategies which affect N dynamics. Initially it will be important to develop N management strategies for these systems. We propose research to study how nitrogen fertilizer is managed in these systems to reduce N losses (and therefore costs) and maintain yield. Treatments will involve N fertilizer applied at different rates and times. Within each plot, an N rate trial was established with 5 N rates ranging from 0 to 215 lb N/ac.

Greenhouse gas (GHG-methane and nitrous oxide) emissions were also measured from these systems. These measurements will be conducted in a similar manner as we have done in previous years using vented chambers and sampling frequently during critical management practices and at least weekly during other periods.

Results

Rice grain yields were good and averaged 9400 lb/ac across all treatments. Water management had no significant effect on yields (Fig. 1).

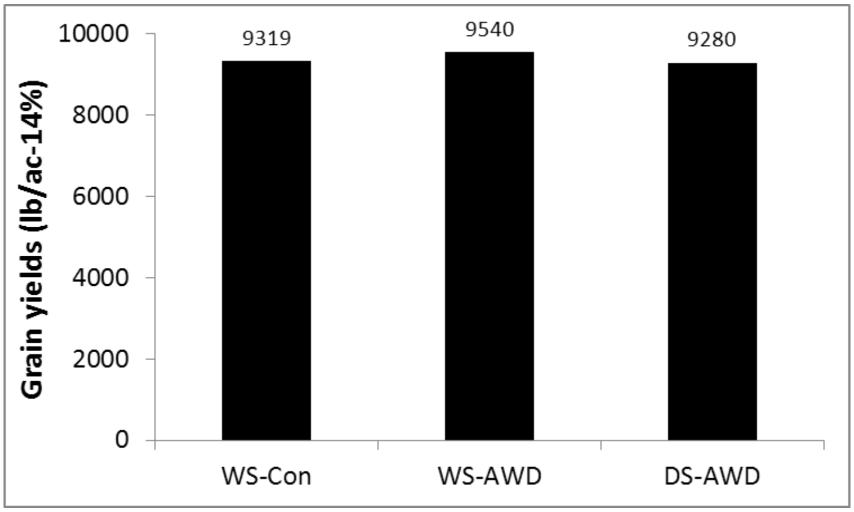


Figure 1. 2013 rice grain yields (adjusted to 14% moisture) from main plot.

In the N rate trial, the response to N was similar among the different water management treatments (Fig. 2). When no fertilizer N was added yields averaged 4100 lb/ac across treatments. In all water management treatments the N rate that provided the highest yields (9300 lb/ac across all treatments) was 160 lb N/ac.

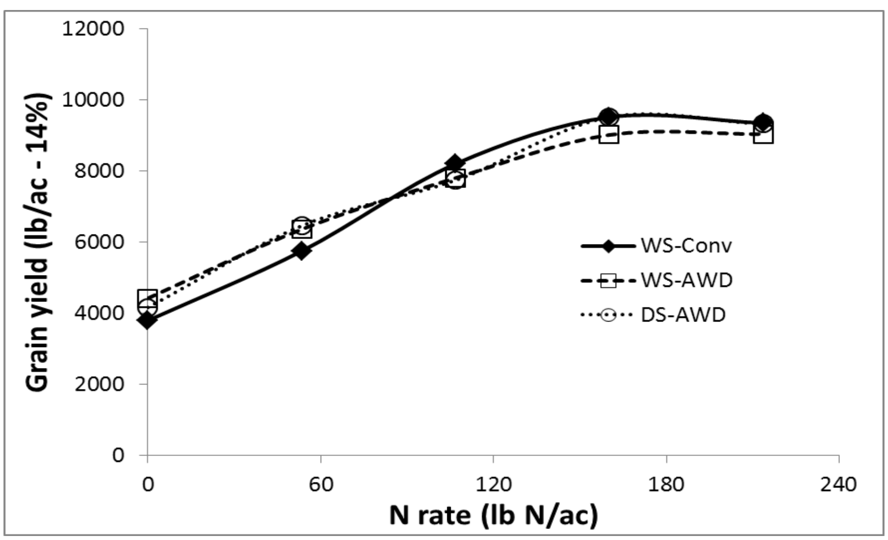
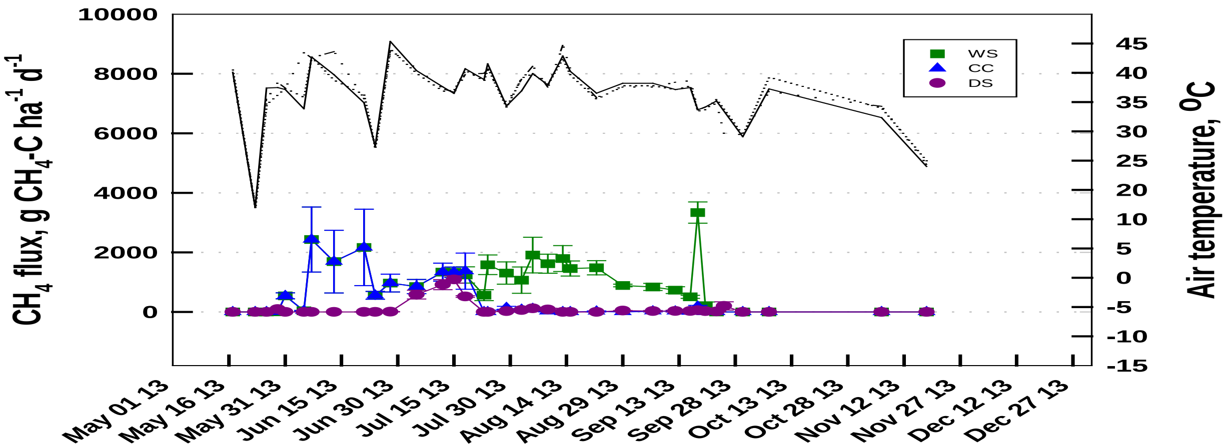


Figure 2. Grain yield response to various N rates in 2013.

Greenhouse gas (GHG) emissions varied considerably between treatments – especially for methane (CH_4). The WS-Conv treatment which was flooded the entire season had much higher CH_4 emissions (144 kg CH_4-C ha^{-1}) than the other treatments which were 68 and 17 kg CH_4-C ha^{-1} for the WS-AWD and DS-AWD, respectively (Fig. 3, Table 1). N_2O emissions were low for all treatments.



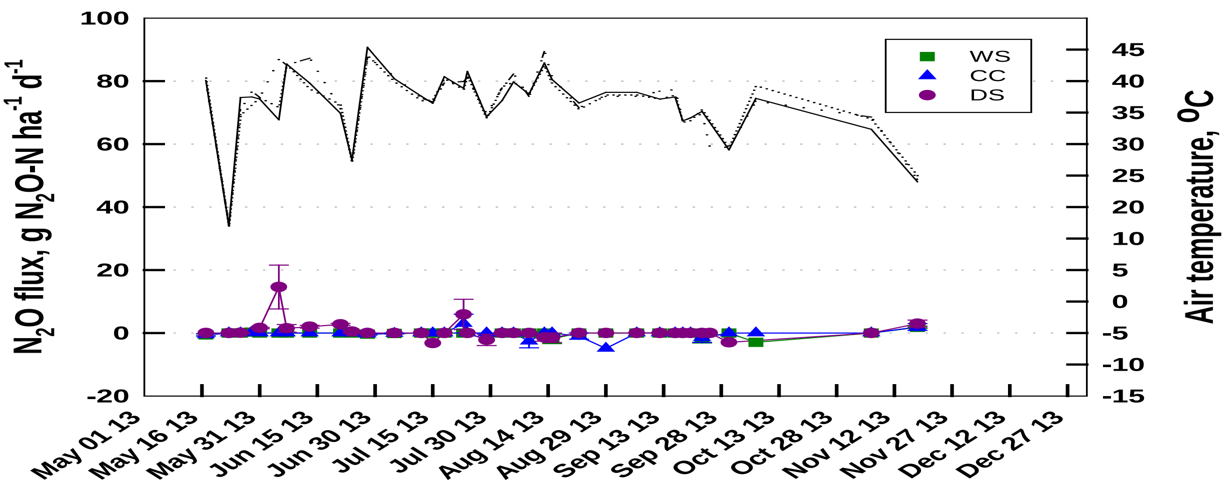


Figure 3. Methane (top) and N2O (bottom) fluxes for each treatment in 2013 (WS=WS-Conv; CC=WS-AWD; DS=DS-AWD).

Table 1. Seasonal GHG emissions and GWP in wet and drill seeded rice system under different water management during 2013 cropping. (RES site; WS and CC emission estimates were from combined WS and CC)

Water management	CH_4 emission[1]		N_2O emission[1]		GWP[1]	
	kg CH_4-C ha^{-1} $season^{-1}$	kg CO_2 eq ha^{-1} $season^{-1}$	kg N_2O-N ha^{-1} $season^{-1}$	kg CO_2 eq ha^{-1} $season^{-1}$	kg CO_2 eq ha^{-1} $season^{-1}$	kg CO_2 eq Mg^{-1} $season^{-1}$
WS-Conv	144*a*	4793*a*	-0.001*b*	-0.508*b*	4793*a*	450*a*
WS-AWD	68.3*b*	2280*b*	-0.001*b*	-0.550*b*	2280*b*	228*b*
DS-AWD	17.0*c*	567*c*	0.001a	0.374*a*	567*c*	53.4*c*

[1] GHG and GWP emissions followed by same letter or no letter are not significantly different at P<0.05.

Future work

These results are different than have been observed previously where it has been shown that yields are reduced if the soil becomes aerobic. While this is encouraging from a water-use, heavy metal and environmental standpoint, more research needs to be conducted in this area. Further, these research plots are relatively small and even if these systems are viable at this scale it may be very difficult to implement at a field or irrigation district level. We plan to continue this research at the RES in 2014. If results remain encouraging then we plan to address the other issues of scale later.

PUBLICATIONS (Rice publications - 2011 - 2013):

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2. Linquist, B.A., M.D. Ruark and J.E. Hill. 2011. Soil order and management practices control soil phosphorus fractions in managed wetland ecosystems. Nutrient Cycling in Agroecosystems 90:51-62.
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4. Krupa, M., R.G.M. Spencer, K.W. Tate, J. Six, C. van Kessel and B.A. Linquist. 2012. Controls on dissolved organic carbon composition and export from rice dominated systems. Biogeochemistry Journal 108:447-466.
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7. Linquist, B.A., K.J. van Groenigen, M.A. Adviento-Borbe, C. Pittelkow and C. van Kessel. 2012. An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biology 18:194-209 doi:10.1111/j.1365-2486.2011.02502.x
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11. Linquist, B.A., M.A. Adviento-Borbe, C.M. Pittelkow, C. van Kessel and K.J. van Groenigen. 2012. Fertilizer management practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. Field Crops Research 135:10-21.
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14. Simmonds, M.B., R.E. Plant, J.M. Peña-Barragán, C. van Kessel, J. Hill and B.A. Linquist (2013). Underlying causes of yield spatial variability and potential for precision management in rice systems. Precision Agriculture 14:512-540.
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16. Pittelkow, C.M., M.A. Adviento-Borbe, J.E. Hill, J. Six, C. van Kessel, B.A. Linquist (2013). Yield-scaled global warming potential of annual nitrous oxide and methane emissions from continuously flooded rice in response to nitrogen input. Agriculture, Ecosystems and Environment 177:10-20.

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18. Adviento-Borbe, M.A., C.M. Pittelkow, M. Anders, C. van Kessel, J.E. Hill, A.M. McClung, J. Six, and B.A. Linquist. (In Press, 2013). Optimal fertilizer N rates and yield-scaled global warming potential in drill seeded rice. Journal of Environmental Quality.
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CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

1. In 2012 we identified 31 fields and in 2013 – 24 fields. From each field, soils samples (from the top, middle and bottom checks), water samples (twice each season from inlet) and flag leaf samples at heading were all analyzed for K. In addition, each grower was asked about historical (past 5 years) yields from fields, straw management and winter flooding practices.

   Soil K values ranged from 35 to 350 ppm (critical level-60 ppm). There was no relationship between soil K values and the amount of K that had been added and removed (based on recent history data). The primary pattern we saw was that soil K values were lowest in the south-east, followed by north-east and north west. Highest values were in south-west. All fields below 60 ppm (critical value) were on the east side of the valley.

   The critical flag-leaf K value is 1.2%. When Soil K values were below the critical value of 60 ppm then ½ of the flag leaves sampled had K values below the critical range. However, when soil K ranged from 60 to 120 ppm, 8 flag leaf samples had K levels below the critical range. This data suggest that K fertility may need to be considered at K levels below 120 ppm.

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2. Irrigated croplands can be a major source of nitrate (NO_3–N) in groundwater due to leaching. In California where high NO_3–N levels have been found, the contribution from rice systems has not been determined. The extent of NO_3–N leaching from rice systems was evaluated from: soil cores (0–2m) from eight fields over a four year period (Fig. 1); the fate of ^{15}N fertilizer in replicated micro-plots located in four fields; and regional wells. Soil NO_3–N concentrations were $\leq$ 3.3 mg kg^{-1} (usually <1 mg kg^{-1}) below the root zone (<33 cm). NO_3–N in pore water samples was only observed below the root zone during the first two weeks following the onset of flooding in either the growing season or winter fallow period and was always $\leq$8.4 mg L^{-1}. Fertilizer N accounted for 0 to 11.8% of NO_3–N in pore water samples below the root zone. After one year 2.5% of fertilizer N was recovered as ^{15}N below the root zone (33 – 100 cm). We hypothesize that this downward movement of fertilizer N was been due to NO_3–N leaching in permeable soils

or via preferential flow through cracks in heavy clay soils. Based on a regional assessment, wells that are directly associated with rice all had median NO_2– and NO_3–N levels below 1 mg kg^{-1} (Fig. 1). **These results all indicate that NO_3–N leaching is not a concern for the majority of California rice soils under current crop management practices.**

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   In the summer of 2012, a research site was established to evaluate three different water management practices each replicated three times:

   1. Water-seeded conventional (WS-Conv)
   2. Water seeded with flood maintained till canopy closure – then flush irrigated (WS-AWD)
   3. Drill seeded with continuous flushing (DS-AWD).

   Our findings indicate that yields and optimal N rates are the same for each system; however, methane emissions are much reduced in the AWD systems.