ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
January 1, 2014 - December 31, 2014

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

PROJECT LEADER (include address):
Bruce Linquist, UCCE Rice Specialist, Department of Plant Sciences, University of California, One Shields Ave, Davis, CA 95616
(530) 752-3450;balinquist@ucdavis.edu

PRINCIPAL UC INVESTIGATORS (include departmental affiliation):

COOPERATORS:
Randall Mutters, Cooperative Extension Farm Advisor, Butte County

Chris Greer, Cooperative Extension Farm Advisor, Sutter, Placer and Yuba Counties

Luis Espino, Cooperative Extension Farm Advisor, Colusa, Glenn and Yolo Counties

Michelle M Leinfelder-Miles, Cooperative Extension Farm Advisor; San Joaquin, Sacramento, Solano, and Contra Costa Counties

LEVEL OF 2014 FUNDING: $89,525

OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:
The 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 2014 the following specific objectives were addressed.

1. Determine the potassium status of rice soils.
2. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.
3. Understand and quantify rice yield variability in the Sacramento Valley

SUMMARY OF 2014 RESEARCH (major accomplishments), BY OBJECTIVE:

1. Determine the potassium status of rice soils.

In 2012 and 2013, 55 rice fields were identified. 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 considered to be 1.2%. When soil K values were below the critical value of 60 ppm then 50% of the flag leaves sampled had K values below the critical range and when soil K ranged from 60 to 120 ppm, 8 flag leaf samples (24%) had K levels below the critical range (Fig. 1). Based on this data, we suggest when soil K levels are below 120 ppm, that K fertilizer should be considered.

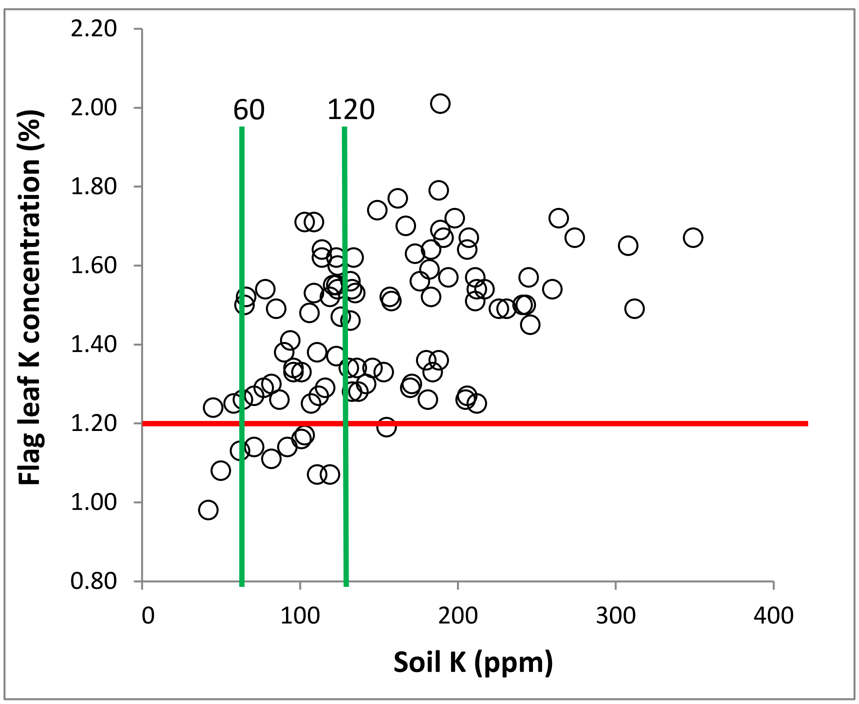


Figure 1. The relationship between soil K and flag leaf K values in 2012 and 2013 fields where K fertilizer was not applied.

There was a significant difference in the concentration of K in irrigation waters. 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.

In 2014, soils from all fields and checks were sent to lab for complete analysis. Data is currently being analyzed and we anticipate publication of results in 2015. In addition, findings from this research will be developed into a format that is useful for growers and made available on-line as well as other outlets in order that growers can further improve their K management.

2. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

While the conventional system of growing rice under continuously flooded conditions produces good grain yields and maintains high nitrogen use efficiency (NUE), California rice growers need to be prepared for situations where they might face legislative pressure to implement alternative water management strategies. For example, concerns have been raised about the high greenhouse gas emissions associated with continuously flooded rice fields, as well as arsenic uptake by rice plants and methyl-mercury formation in flooded soils. The alternation of wet (flooded) and dry (drained) conditions, known as AWD, has the potential to mitigate some of the aforementioned problems. While these problems don't currently necessitate an alternative water management strategy, it is important to evaluate the agronomic viability of AWD as a potential option.

During the 2014 growing season an experiment involving three water management treatments was continued: water-seeded continuous flood (WS-Conv), water-seeded AWD (WS-AWD), and drill-seeded AWD (DS-AWD). The latter treatment involved flush-irrigating the field every time the volumetric water content dropped to ~35%, and the water-seeded AWD treatment was flooded until canopy closure and then had similar flush-irrigation. Nitrogen rate trials were established in each main treatment plot, in order to determine how the nitrogen response differed among treatments. Greenhouse gas emissions (GHG-methane and nitrous oxide) were monitored daily to weekly using non-flow-through vented flux chambers. Soil samples were taken periodically throughout the growing season and analyzed for NH_4^+ and NO_3^- levels. At the end of the season, plots were harvested, yields were determined, and samples were processed for analysis of N uptake.

As in the 2013 growing season it was found that grain yields were similar among all three water management treatments (Fig. 1). The N trial yields are not available yet for the 2014 growing season, but during the 2013 growing season the N response curves for all three treatments were also similar (Fig. 2, suggesting similar NUE among treatments.

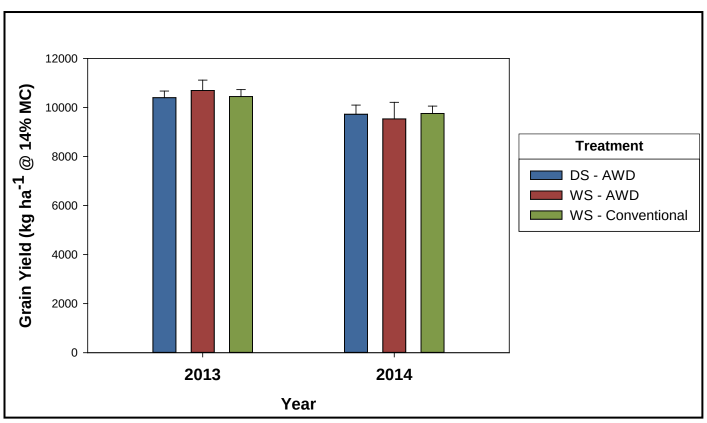


Figure 1: Rice grain yields (mean ± SE) of the three water management treatments for the 2013 and 2014 growing seasons

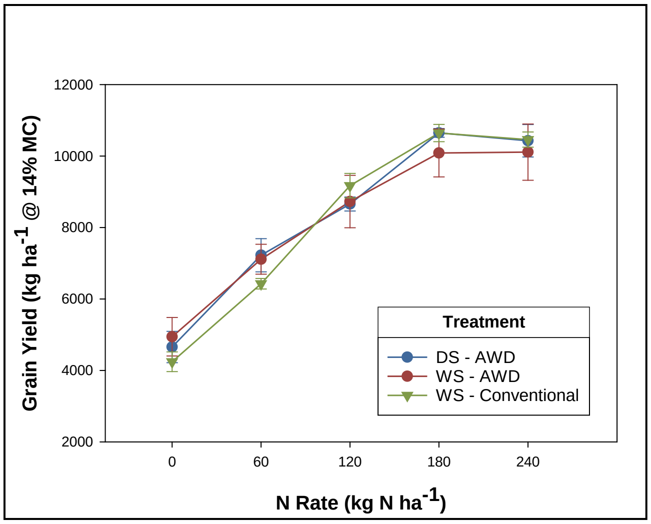


Figure 2: Nitrogen response curves for the water management treatments (mean ± SE) for the 2013 growing season (2014 data not available yet)

Nitrous oxide (N_2O) emissions were low for all three treatments, but methane (CH_4) emissions were reduced in the WS-AWD treatment relative to the WS-Conv (Table 1, Fig. 3), and the DS-AWD treatment reduced CH_4 emissions even further. As a result the global warming potential (GWP) of the DS-AWD treatment was the lowest followed by the WS-AWD treatment (Fig. 4; Table 1). These results indicate that AWD can maintain rice grain yields and high NUE while significantly reducing the GHG emissions associated with rice cultivation.

Table 1: Mean (SE) cumulative CH_4 and N_2O emissions for each water management treatment with total GWP and yield-scaled GWP for the 2014 growing season

	CH_4 (g CH_4-C ha^{-1})	**N_2O (g N_2O-N ha^{-1})**	**GWP (kg CO_2-eq ha^{-1})**	**Yield Scaled GWP (kg CO_2-eq kg^{-1} grain)**
DS - AWD	29874 (11418)	363 (181)	641 (147)	0.067 (0.015)
WS - AWD	58714 (21029)	-28.7 (1.43)	1414 (499)	0.141 (0.048)
WS - C	142176 (18783)	-26.0 (20.0)	4047 (538)	0.424 (0.062)

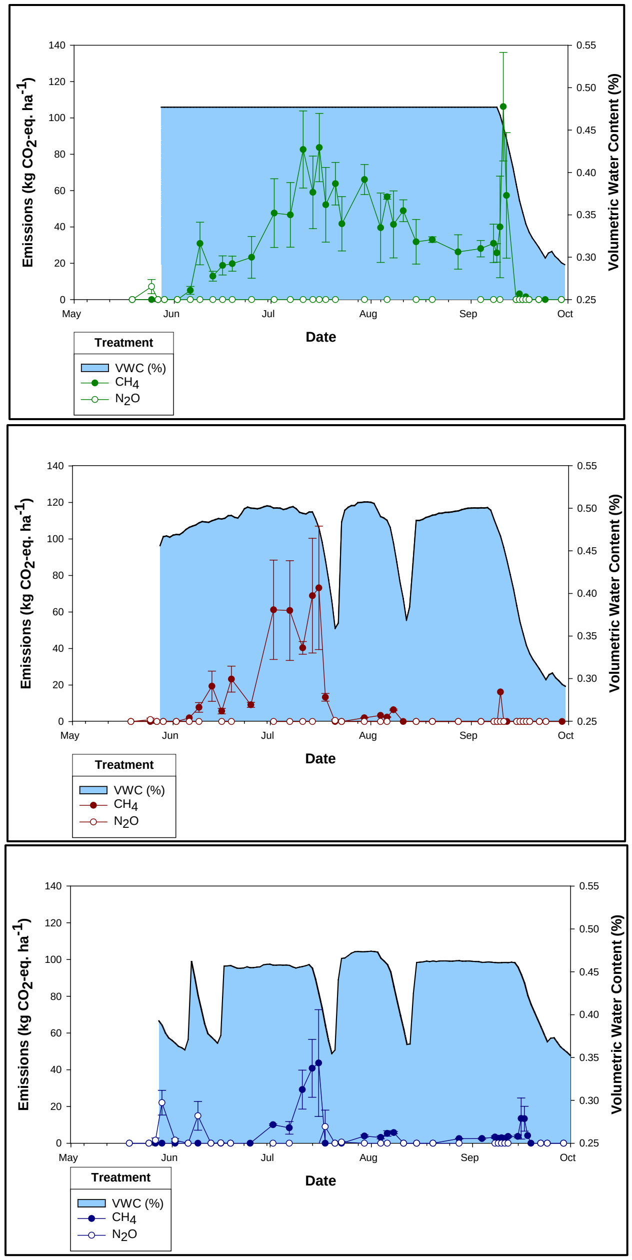


Figure 3: Soil moisture and greenhouse gas emissions (CH_4 and N_2O - means ± SE) and water management during the 2014 growing season for the water-seeded continuous flood (top), water-seeded AWD (middle), and drill-seeded AWD treatments.

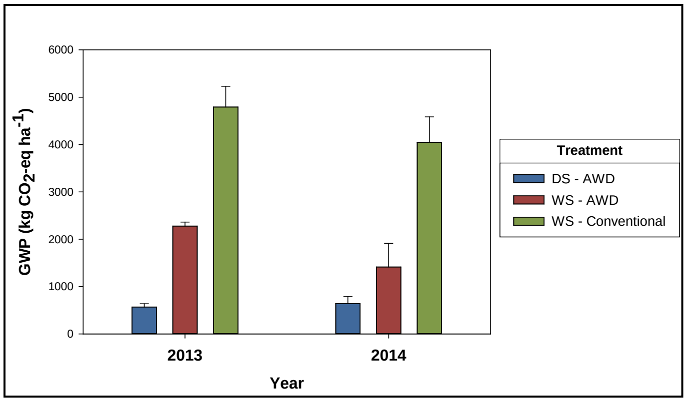


Figure 4: GWP for the three water management treatments (mean ± SE) for the 2013 and 2014 growing seasons

3. Understand and quantify rice yield variability in the Sacramento Valley

California rice yields are amongst the highest in the world; however over the past 15 to 20 years yields have stagnated. Our objective is to identify ways to further increase yields through improved management that optimizes the yield potential of the varieties being developed. Broadly the objectives of this research are as follows:

- Create a database of Statewide Variety Trials, state and county yield data, grower yields, and other yield data that is accessible to multiple research groups for analysis.
- Analyze yield trends across time, estimating the impact of soils, management, and climate variability.
- Conduct a Yield Gap Analysis
- Highlight areas of improvement or future research in support of increased yield and yield stability in CA rice production.

Initially this project will focus on understanding year to year yield variation. Despite the yield stagnation just mentioned there has been considerable yield variation from year to year. In order to better understand this yield variation, it is critical to understand the impact of various climate variables on yields. Secondly, we are conducting a Yield Gap Analysis (YGA) of California rice systems. A YGA identifies the maximum yields possible (yield potential) and compares this to the yields that are being achieved. The difference between these two values is the yield gap. Our objective is to narrow the yield gap through improved management.

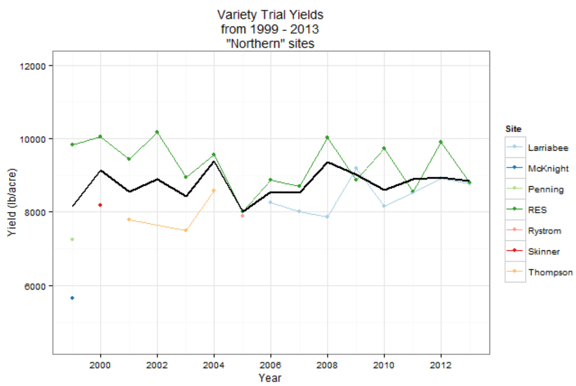
In 2014, much of the work on this project was collecting and compiling data for analysis and putting it into a data base for analysis. Specifically, our objectives were:

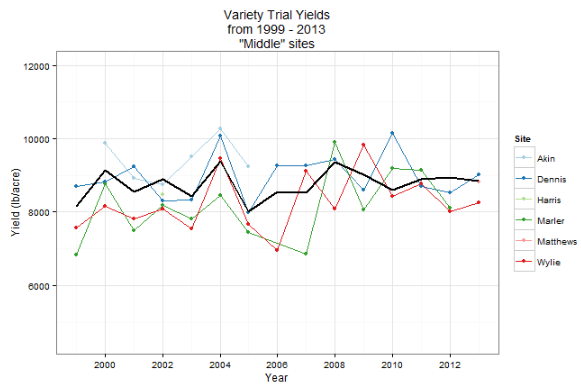
- Create a database of UCCE Statewide Variety Trials, state and county yields, and grower yields.
- Create a data base of climate and soils data that is paired with each of the yield data bases.

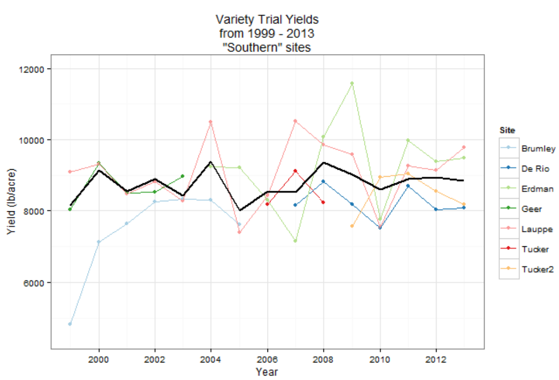
Our 2014 progress to date is as follows:

- Compiled all Statewide Variety Trial data from 1999-2013 into a central database, including error checking (approximately 21,000 data points)
- Linked yield data to site-specific daily climate (CIMIS and DAYMET) and soils (SSURGO) data (approximately 3 million data points)
- Created a procedure to calculate climate variables (e.g. – average temperature during flowering) specific to each data point in the Statewide Variety Trials.
- Conducted preliminary data exploration as follows.

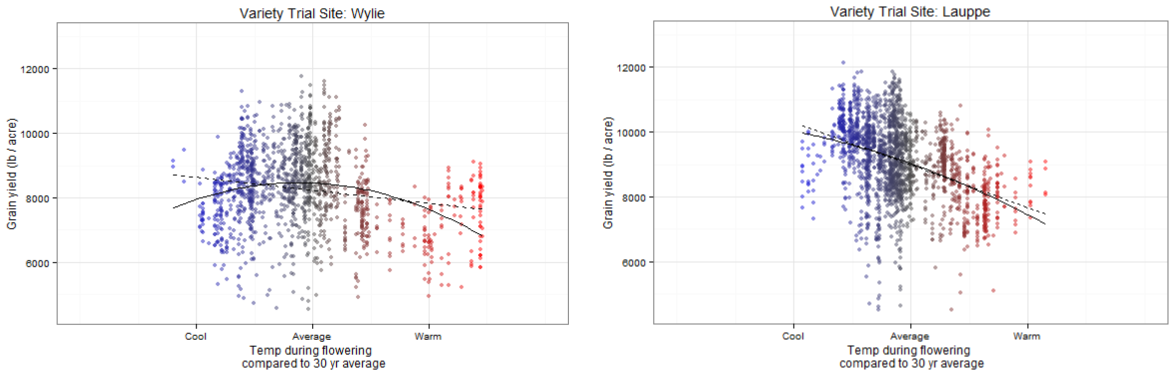
Yields from the Statewide Variety Trials mirror yearly statewide average rice yields, indicating that the Variety Trial data will be a suitable comparison for statewide trends. Year to year variability in average yields for each site is relatively high, though some sites consistently yield greater than others. Temperature, specifically during flowering, appears to affect yields across sites. This will be the focus of future work.







Figures 1-3. Yield trends from the time period 1999-2013, divided by geographic location of the trial site. The dark black line is the average yield across all sites. Overall variability is high, but indicates this dataset will be suitable for making inferences about statewide trends.



Figures 4-5. Yields from two variety trial locations (Wylie and Lauppe) plotted against the temperature during flowering. Temperature was computed as the difference between each year's temperatures and the 30 year average temperatures. The difference between "Cool" and "Warm" is approximately 4°C (7-8°F) daily minimum temperature. There is a clear impact of temperature during flowering on yield, though site differences exist.

In 2015 we plan the following:

- Complete analysis of Statewide Variety Trial data and present findings to Rice Breeders at the RES, as well as other groups.
- Begin collection of historic yield data from farmers in Butte, Colusa, Glenn, and Sutter counties.
- Complete the Yield Gap Analysis
- Make suggestions for areas where additional knowledge is needed, or future research is warranted.
- Outline a procedure to make the database created available and easily updated with current yield data.

PUBLICATIONS (Rice publications 2012-14):

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2. Pittelkow, C.M., A.J. Fischer, M.J. Moechnig, J.E. Hill, K.B. Koffler, R.G. Mutters, C.A. Greer, Y.S. Cho, C. van Kessel, C. and B.A. Linquist. 2012. Agronomic productivity and nitrogen requirements of alternative tillage and crop establishment systems for improved weed control in direct-seeded rice. Field Crops Research 130:128-137.
3. Lundy, M.E., D.F. Spencer, C. van Kessel, J.E. Hill and B.A. Linquist. 2012. Managing phosphorus fertilizer to reduce algae, maintain water quality, and sustain yields in water-seeded rice. Field Crops Research 131:81-87.
4. 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.
5. Liang, X.Q., H. Li, S.X. Wang, Y.S. Ye1, Y.J. Ji, G.M. Tian, C. van Kessel and B.A. Linquist. 2013. Nitrogen source and rate influence yield-scaled global warming potential in rice cropping systems. Field Crops Research 146:66-74.

6. 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.
7. 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.
8. Adviento-Borbe, M.A., C.M. Pittelkow, M. Anders, C. van Kessel, J.E. Hill, A.M. McClung, J. Six, and B.A. Linquist. (2013). Optimal fertilizer N rates and yield-scaled global warming potential in drill seeded rice. Journal of Environmental Quality 42:1623-1634.
9. Linquist, B.A., L. Liu, C. van Kessel, and K.J. van Groenigen. (2013) Enhanced efficiency nitrogen fertilizers for rice systems: meta-analysis of yield and nitrogen uptake. Field Crops Research 154: 246-254.
10. Pittelkow, C., M.A. Adviento-Borbe, C. van Kessel, J. Hill, B. Linquist. (2014). Optimizing rice yields while minimizing yield-scaled global warming potential. Global Change Biology 20:1382-1393.
11. Lundy ,M. E., J.E. Hill, C. van Kessel, D. A. Owen, R. M. Pedroso, L. G. Boddy, A. J. Fischer, and B. A. Linquist. (2014). Site-specific, real-time temperatures improve the accuracy of weed emergence predictions in a direct-seeded rice system. Agricultural Systems 123:12-21.
12. Liang, X.Q., T. Harter, L. Porta, C. van Kessel, and B.A. Linquist. (2014) Nitrate leaching in Californian rice fields: a field and regional scale assessment. Journal of Environmental Quality: 43:881-894.
13. Linquist, B.A., M. Ruark, R. Mutters, C. Greer, and J. Hill. (2014). Nutrients and sediments in surface runoff water from rice fields: Implications for nutrient budgets and water quality. Journal of Environmental Quality 43:1725-1735.
14. Spencer, D. and B.A. Linquist. (2014) Reducing rice field algae and cyanobacteria by altering phosphorus fertilizer applications. Paddy and Water Environment 12:147-154.
15. Pittelkow, C.M., Y. Assa, M. Burger, W.R. Horwath, R.G. Mutters, C.A. Greer, L.A. Espino, J.E. Hill, C. van Kessel, B.A. Linquist. (2014). Nitrogen management and methane emissions as affected by alternative establishment practices in direct-seeded rice. Agronomy Journal 106:968-980.
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17. Brodt, S., A. Kendall, Y. Mohammadi, A. Arslan, J.Yuan, I. Lee, B. Linquist. (2014) Life cycle greenhouse gas emissions in California rice production. Field Crops Research 169:89-98.
18. Simmonds, M.B., M. Anders, M.A. Adviento-Borbe, C. van Kessel, A. McClung, and B.A. Linquist. (In Press). Seasonal CH_4 and N_2O emissions and plant growth characteristics in direct seeded rice systems. Journal of Environmental Quality.
19. Nalley, L. L., M.M. Anders, K.F. Kovacs, and B. Linquist (In Press) The economic viability of alternate wetting and drying (AWD) irrigation in rice production in the mid-south. Agronomy Journal

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Objective 1. Determine the potassium status of rice soils.

Plant, soil and water data from the 55 fields sampled in 2012 and 2013 have all been analyzed. In brief, 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) suggesting that it is not a good management strategy to try to build up soil K but rather apply the amount needed. 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 considered to be 1.2%. When soil K values were below the critical value of 60 ppm then 50% of the flag leaves sampled had K values below the critical range and when soil K ranged from 60 to 120 ppm, 8 flag leaf samples (24%) had K levels below the critical range (Fig. 1). Based on this data, we suggest when soil K levels are below 120 ppm, that K fertilizer should be considered.

There was a significant difference in the concentration of K in irrigation waters. 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.

Data is currently being analyzed and we anticipate publication of results in 2015. In addition, findings from this research will be developed into a format that is useful for growers and made available on-line as well as other outlets in order that growers can further improve their K management.

Objective 2. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

In both 2013 and 2014, yields among the three water management treatments were the same. Similarly the optimum N rate required to achieve maximum yields was similar among treatments. Relative to the water seeded conventional system, the Global Warming Potential (GWP) was reduced by approximately 60% in the WS-AWD and by over 80% in the DS-AWD. While such results are encouraging and show the possibility of these systems, it is not clear how easy it would be to implement at the field scale.

Objective 3. Understand and quantify rice yield variability in the Sacramento Valley

In 2014, the focus of our efforts was compiling a useable database in order to accomplish our objectives. Specifically we:

- Compiled all Statewide Variety Trial data from 1999-2013 into a central database, including error checking (approximately 21,000 data points)
- Linked yield data to site-specific daily climate (CIMIS and DAYMET) and soils (SSURGO) data (approximately 3 million data points)
- Created a procedure to calculate climate variables (e.g. – average temperature during flowering) specific to each data point in the Statewide Variety Trials.
- Conducted some preliminary data exploration.