ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
January 1, 2022 - December 31, 2022

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

PROJECT LEADER:

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OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

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 2022 the following specific objectives were addressed.

1) Impacts of fallow and crop rotation on N fertility management
2) "No-till" planting into ground previously fallowed and worked ground.
3) Alternative N management strategies

SUMMARY OF 2022 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1. Impacts of fallow and crop rotation on N fertility management
In California rice systems, rice is sometimes rotated with other crops. This is most common in the southern portion of the Sacramento Valley. Also, increasingly we are seeing an increase in rice water sales, which leaves the soil fallow for a year. In both of these cases, farmers often report higher rice yields. Higher rice yields may be due to various factors such as diseases, pests, weeds or nutrient management. Importantly, it is critical to understand if such fields need to be managed differently in terms of N fertility to optimize yields and reduce N losses. Very preliminary results (based on only a few samples) suggest that this variability may be related to soil phenol content. High soil phenols are often associated with long periods of flooding and residue decomposition under flooded conditions. If this is the case, N management practices are likely to be different between these types of fields.

The objective of this research was to determine if N management practices need to be changed based on the previous crop and fallow season in order to maximize yields and N-use efficiency.

Methods
2022 was the second year of this study. In 2022, we ran the experiment like we ran the 2021 experiment. A replicated experiment was set up at the Rice Experiment Station (RES). Using a split-plot design, the two main plot treatments will be (1) continuous rice with winter flooding and (2) previous year field was fallowed or grown to upland crop and had no winter flooding). Subplots were a range of N rates (0, 80, 107, 134, 160 and 187 lb N/ac). The highest N rate was high enough to ensure sufficiency for maximum yields. These treatments allowed for an indirect determination of fertilizer N recovery [(N uptake fertilized plot – N uptake control)/fertilizer N applied]. In addition, ^{15}N labelled fertilizer will be applied as both preplant and top-dress in micro-plots, to directly determine the fate of applied N. M-206 was the planted variety.

Soil and plant tissue samples were taken. Soil samples (0-15cm) were taken preplant and plant samples at mid-tiller (about 35 DAP), PI, heading and harvest maturity (for yield determination). Plant samples will be analyzed for N content. Soil samples were dried and analyzed for phenols.

In a more extensive study, we identified 4 paired commercial fields. The paired fields consisted of one field that has been in continuous rice and winter flooding and the other field will be a field coming out of rotation with an upland crop or was fallow the previous year. Soil samples were taken from each field for phenol analysis.

In addition to the above measurements, we are quantifying GHG emissions from fallowed and continuous rice fields. We hypothesis that methane emissions will be lower in the fallowed plots because much of the straw decomposed during the fallow period.

Results

We can report on 2021 yields, N uptake and disease severity and 2022 yields and disease severity.

In both years' yields were higher in fallowed rice compared to continuous rice (Fig. 1). In 2022, this yield differential could be made up by adding more N fertilizer; however, in 2021 it was not possible to make up the yield differential with more N fertilizer. Why are yields higher in fallowed fields? At least two reasons. First, higher yields after may be due to less disease. We found significantly less stem rot incidence in rice after fallow than after rice (Fig. 2). Second in the fallow treatment, we saw more N availability from the soil after panicle initiation compared to the continuous rice treatment (Fig 3). Fertilizer N uptake was the same between treatments but the fallow had a greater late season N supply from the soil. From a management perspective, this suggests that less N needs to be applied – especially top-dress N in fields coming out of a fallow.

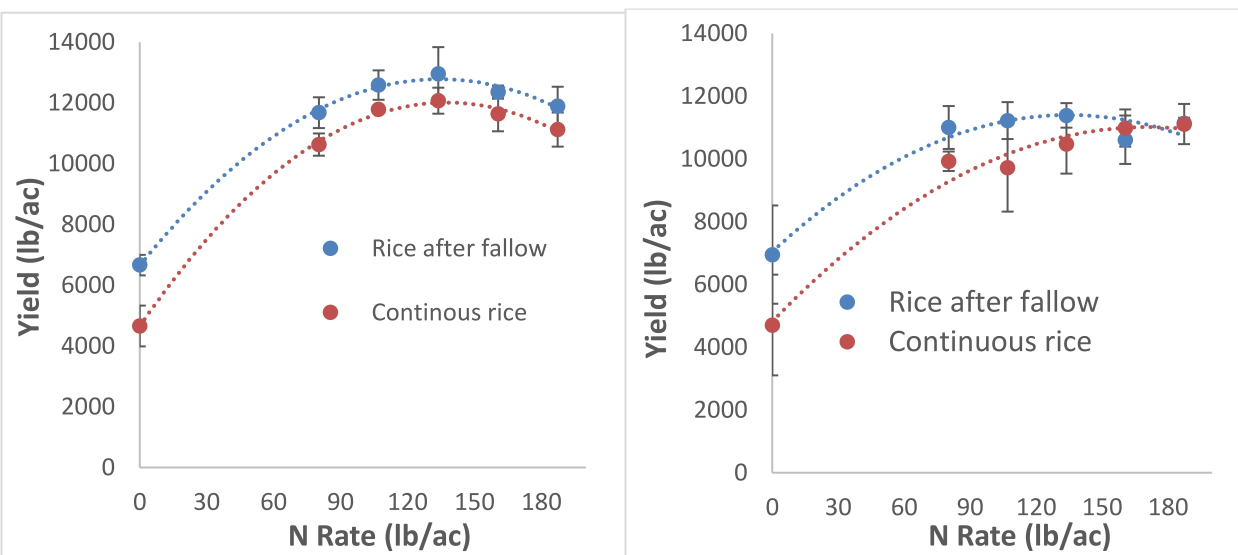

Figure 1. Rice yield in 2021 (left) and 2022 (right) in rice after fallow and continuous rice as affected by N rate.

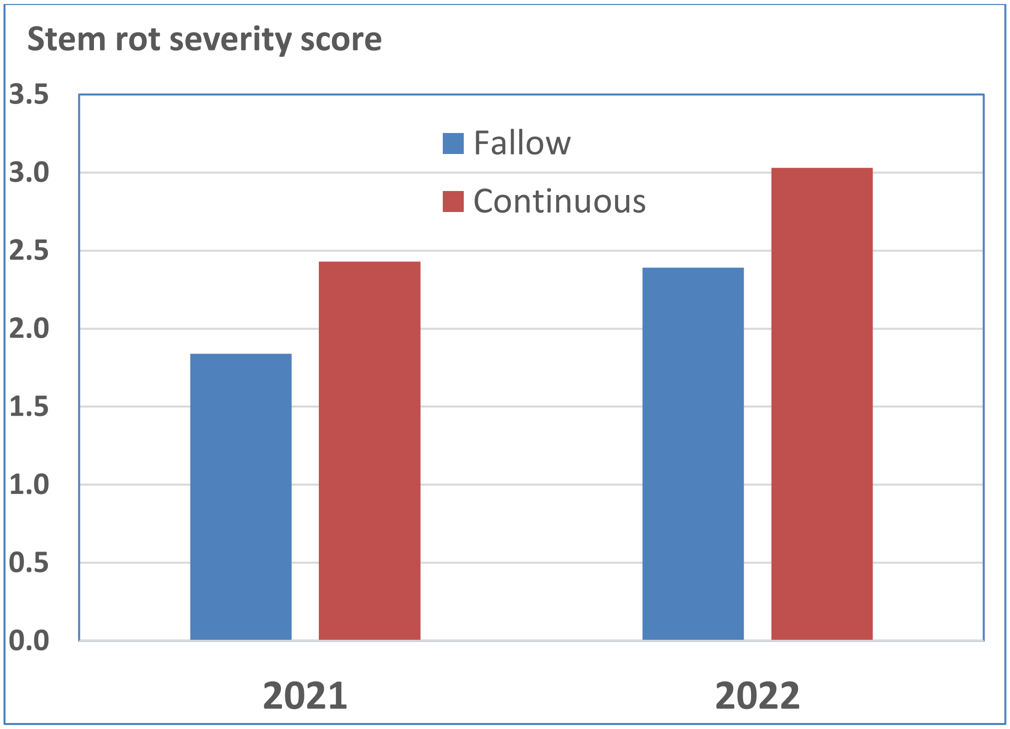

Figure 2. 2021 and 2022 stem rot severity scores of rice following rice or following a fallow.

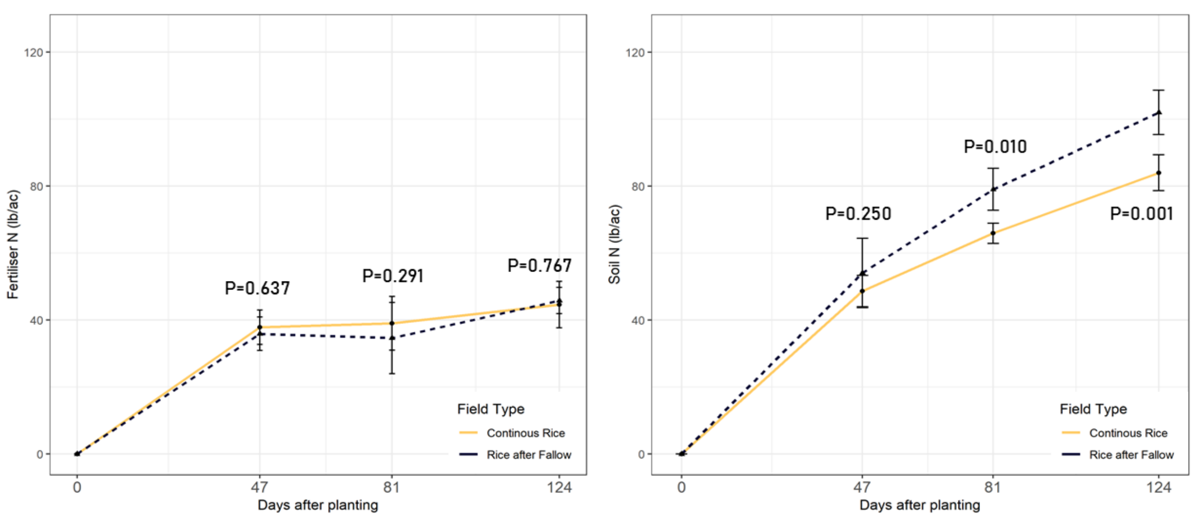

Figure 3. Source of plant N uptake in fallow and continuous rice treatments. Results are from 15N labeled. treatments

Going forward

We plan to continue this research at the RES in 2023. One of the things that we need to better quantify and understand is the differential yield response between the two years. A third year would help us better understand this. We also have our plant and soil samples in the lab for analysis and will analyze those data when they become available.

Objective 2. "No-till" planting into ground previously fallowed and worked ground

Background

In four of the past eight years, 10-50% of rice ground has been fallowed due to either water sales or heavy rains during the planting season. In many cases, growers take the opportunity to work the ground during the summer fallow period. The ground is often worked to the point where it has been leveled.

Doing all of this land preparation the previous year, leaves open the possibility that a grower could kill the weeds and then flood and plant the field without any further tillage. The benefits of this would be:

1. No tillage costs in the current year
2. Ability to plant earlier
3. The possibility of much reduced weeds. It is possible that weed seeds near the surface would have germinated during the past year or have been lost due to predation.

While these benefits may be realized, we recognize that there may be considerable other challenges and that yields may not be adequate to make this an economically viable option. We did a "proof of concept" trial at the RES a few years ago. In that study, due to heavy spring rains, planting was delayed until June 14 and thus overall yields were low. However, yields were similar between the conventional till (CT) (70.5 cwt/ac) and the "no-till" (NT) (72.6 cwt/ac). In 2022, our objective was to follow up on this with more rigorous on-farm studies. The studies had to be on-farm because we did not have plots at the RES that had been fallowed.

Methods

In 2022, we conducted a study at three on-farm sites. For the on-farm study, we asked farmers who were going into a fallowed field to leave out 1 acre without tillage. Thus, for each grower, there was a no-till (NT) treatment and the conventional tillage (CT) treatment which was the normal practice of tillage and planting. For the NT treatment, the area was sprayed with a broad-spectrum herbicide in early April when the rest of the field has started to receive the seed-bed preparation. Before flooding, we set up a replicated N rate trial with a range of different N rates from 0 to 225 lb N/ac in both the NT and CT plots. In all cases, urea was broadcast on the soil surface before planting. Plots were large enough to harvest with a small plot combine. In both the NT and CT areas, an area was set up to monitor weeds and other pests. These areas received no pesticides. The system used to monitor weeds did not work out well, however a weed assessment was taken mid-season to quantify weeds in both NT and CT after all herbicides had been applied. Finally, a large 3000 ft2 area was set up take a larger combine yield area as well as examine yield variability. Early in the season (about 3 wk after planting) we took stand establishment counts in each field.

Results

In one field (DeWitt), managing the water was highly problematic throughout the season and this affected the results. Briefly the results can be summarized as follows:

Stand establishment: At two of the three sites, the number of established seedlings was lower in the NT compared to the CT (Fig 4). We feel that this was largely due to wind following planting. May of 2022 was unusually windy. Based on this, our recommendation would be to roll the field in the fallow year to established groves for the seedlings to fall into. Alternatively, using a Leather's practice would also help.

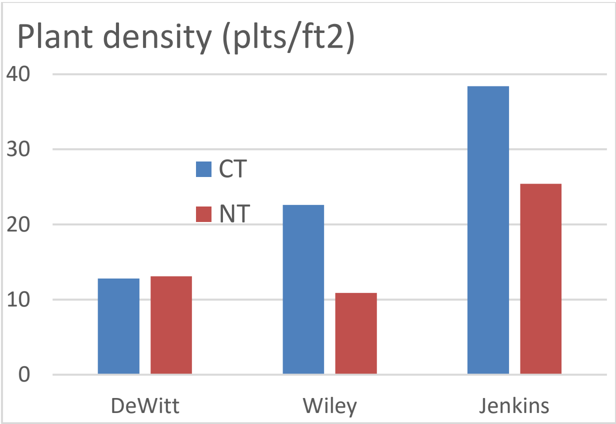

Figure 4. Plant density about 2-3 weeks after planting in no-till (NT and conventional till (CT) treatments.

Weeds: As mentioned earlier, the method used to quantify weeds did not work suitably. However, a late season assessment of weeds showed that at one site, watergrass was higher in the CT treatment and arrowhead was higher in the NT (Fig. 5).

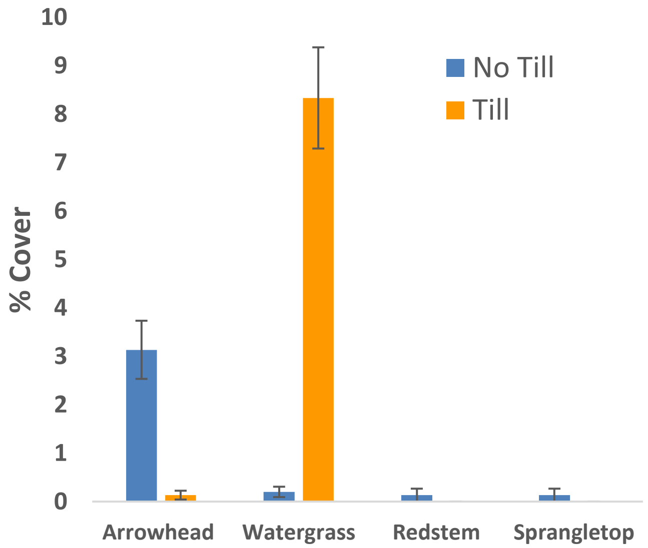

Figure 5. Weed cover after panicle initiation at the DeWitt site.

Pests/Disease: Three was a greater incidence of stem rot (and to a lesser extent for aggregate sheath spot) in the CT treatments (Fig 6). Rice seed midge was a little higher at two of the locations (Fig. 7). Tadpole shrimp was only seen at the Jenkins site and at that site it was very low; however, it was only seen in the CT treatment.

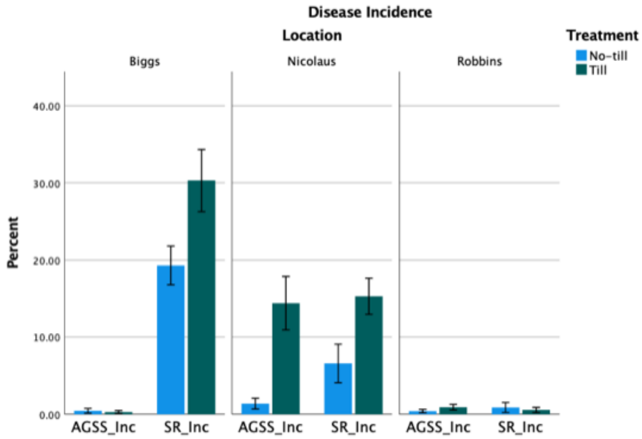

Figure 6. Aggregate sheath spot (AGSS) and stem rot (SR) in till and not till treatments.

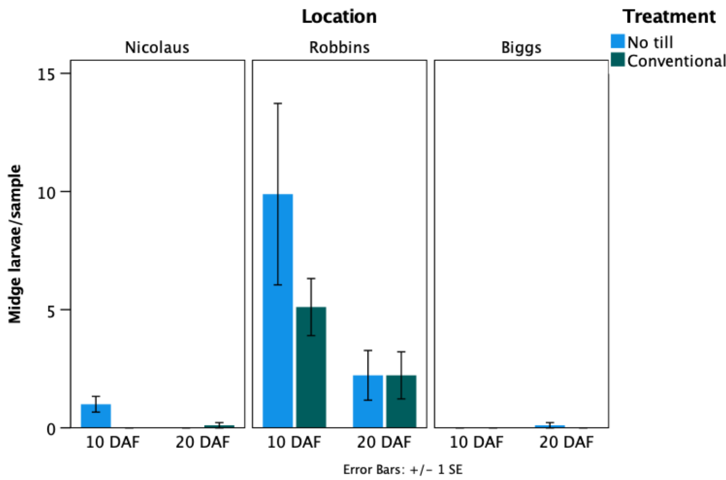

Figure 7. Seed midge in NT and CT treatments.

Yields: Yields were similar to higher in the NT treatment (Fig. 8). In the large 3000 ft2 plot where we took multiple combine harvests to get an average yield and a yield variation, we saw yields were similar at DeWitt (average 87 cwt/ac) and Willey (average 102 cwt/ac) and at Jenkins yields were higher in the NT treatment (110 cwt/ac) compared to the CT treatment (102 cwt/ac). Variability in yields tended to be lower in the NT treatment for reasons I am not clear.

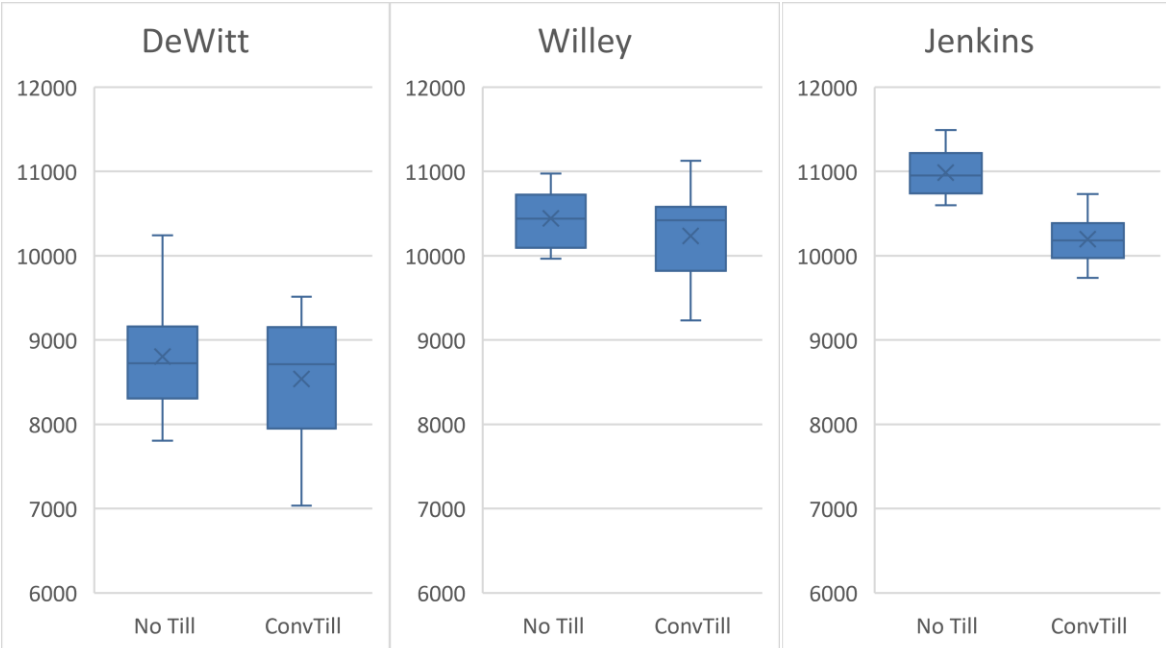

Figure 8. Yield and yield variability between no-till (NT) and conventional till (CT) at three locations. The yield average and variability were taken from 14 small plot combine harvests (150 ft^2 each).

Response to N: The data on yield response to N fertilizer was only good for two sites. At one location (DeWitt), the water drained from the field too soon which confounded the N trail data. At the Willey site yields were higher in the CT regardless of N rate, but the optimum N rate (175 lb N/ac) was similar (Fig. 9). At Jenkins, yields were higher in the NT treatment, which required 175 lb N/ac to achieve the highest yields. In the CT treatment the highest yields were achieved with 125 lb N/ac.

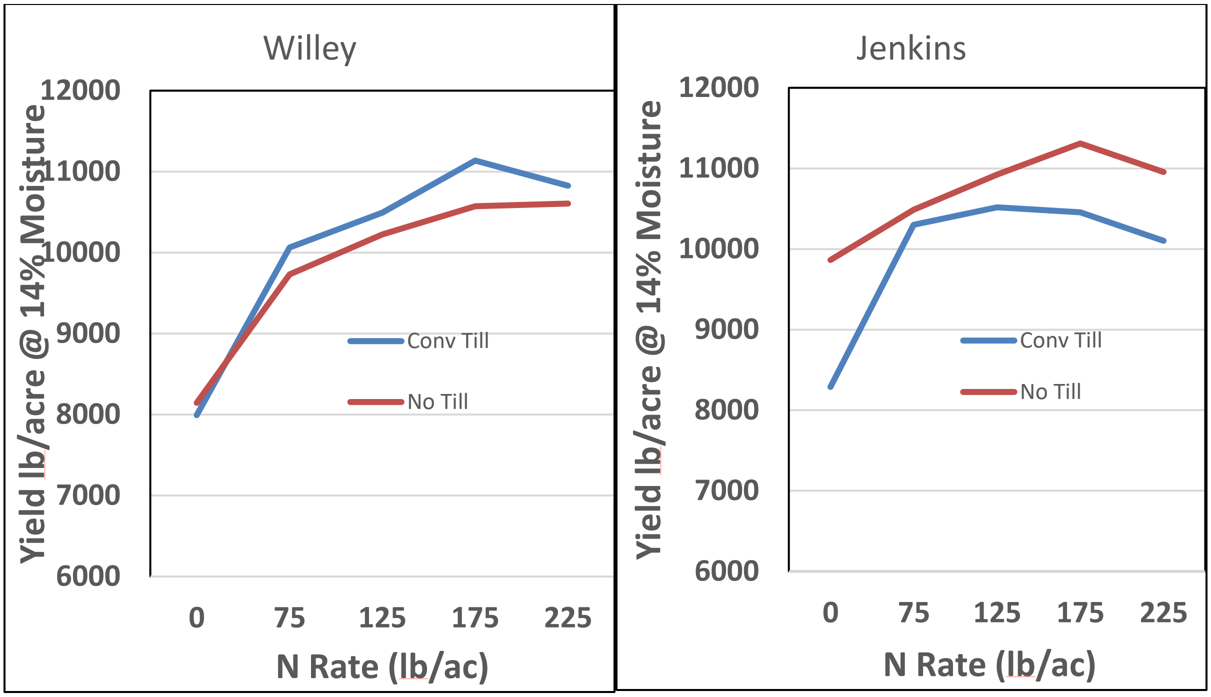

Figure 9. Yield response to N at two sites in no-till (NT) and conventional till (CT) treatments.

Going forward

We found these initial results very encouraging. Some lessons learned were:

- that it would be good to roll the field as a final pass during the fallow year. This would help with a more uniform stand establishment. A leather's method may also help.
- Need to kill all weeds in the field before flooding (do not assume the flooding will kill them)

This practice may offer some growers the ability to get into a field early or have much reduced tillage costs. Another area this practice may be useful for is with a stale seedbed. Stale seedbeds were studied over a decade ago and had great success at controlling herbicide resistant weeds. However, growers have not adopted because it takes too long to get a seedbed ready, flood and drain a field, kill the weeds, reflood and plant. The practice studied here allows growers to flood as soon as temperatures are high enough to germinate weeds seeds.
We want to better understand how this practice affects pests, weeds and diseases. This can be difficult to study on-farm. Therefore, in 2023 we plan to expand this work to the RES where we have a better idea of management. We will also continue to work on-farm as we did in 2022.

Objective 3. Alternative N management strategies
Background
Most rice in California receives the majority of N fertilizer in the form of preplant aqua-ammonia (Aqua). Some top-dress N is applied before planting or delayed by a few weeks. This strategy is efficient and effective. However, in 2019 rains forced many growers to plant their rice before any fertilizer was applied. This resulted in growers having to apply N after planting using a wide range of approaches – some effective and others not.

There has not been any research done in this area in California and growers did not have any recommendations to go on. Given the uncertainty, in 2020, we evaluated six products applied at different times (16 treatments). In 2021, we expanded the treatments (19 total) and conducted it at two locations (RES and on-farm).

Methodology

The study was conducted at the RES in 2020 and the RES and an on-farm location in 2021. No further field research was conducted in 2022, however the data were analyzed.

Results

Some general findings are:

1. Aqua ammonia or urea applied to a dry soil before flooding resulted in the highest yields. This confirms other earlier findings we have made.
2. If a preflood application to a dry soil is not possible, the next best scenario is to split the N rate. The total N rate split at 15-35-35-15% at 3-4-5-6 weeks after planting will likely give the best results. However, the total N rate may need to be increased compared to aqua or urea applied before flooding.
3. Using enhanced efficiency fertilizers such as Super U, Agrotain or Agrocote, had no benefit over applying urea alone. These are expensive fertilizers.

PUBLICATIONS OR REPORTS:

PUBLICATIONS (Rice publications 2020-22):

1. Pedroso, R.M., C. van Kessel, D.D. Neto, B.A. Linquist, L.G. Boddy, R.V. Filho, and A.J. Fisher. (2020). ALS Inhibitor-Resistant *Cyperus difformis* seed germination requires fewer growing degree-days and lower soil moisture. *Weed Science 68:51-62.* https://doi.org/10.1017/wsc.2019.57
2. Murray, A. and B.A. Linquist. (2020). Midseason application of organic fertilizer improves yield and N uptake in rice. *Agronomy Journal* 112:441-449 doi: 10.2134/agronj2019.05.0407
3. Chuong, T., R.E. Plant and B.A. Linquist. (2020). Fertilizer source and placement influence ammonia volatilization losses from water-seeded rice systems. *Soil Science Society of America Journal* 84:784-797 doi.org/10.1002/saj2.20074
4. Wang, H., A. Ghosh, B.A. Linquist, and R.J. Hijmans. (2020). Satellite-based observations reveal effects of weather variation on rice phenology. *Remote Sensing* doi.org/10.3390/rs12091522
5. Eagle, A.J., E.L. McLellan, E.M. Brawner, M.H. Chantigny, E.A. Davidson, J.B. Dickey, B.A. Linquist, T.M. Maaz, D.E. Pelster, C.M. Pittelkow, C. van Kessel, T.J. Vyn, and K.G. Cassman (2020) Quantifying on-farm nitrous oxide emission reductions in food-supply chains. *Earth's Future* doi: 10.1029/2020EF001504.
6. LaHue, G.T. and B.A. Linquist. (2021) The contribution of percolation to water balances in water-seeded rice systems. *Agricultural Water Management* doi.org/10.1016/j.agwat.2020.106445
7. Kanter, J., C. Nicholas, M.E. Lundy, V. Koundinya, M. Leinfelder-Miles, R. Long, S. Light, W. Brim-DeForest, B.A. Linquist, D.H. Putnam, R.B. Hutmacher, C.M. Pittelkow. (2021)

Top Management Challenges and Concerns for Agronomic Crop Production in California. *Agronomy Journal* 113:5254-5270. doi.org/10.1002/agj2.20897.

8. Yuan, S. B.A. Linquist, L.T. Wilson, K.G. Cassman, A.M. Stuart, V. Pede, B. Miro, K. Saito, N. Agustiani, V.E. Aristya, L.Y. Krisnadi, A. Zanon Jr., A.B. Heinemann, G. Carracelas, N. Subash, P.S. Brahmanand, R. Ford, S. Peng, P. Grassini. (2021). A roadmap towards sustainable intensification for a larger global rice bowl. *Nature Communications* 12, 7163 doi.org/10.1038/s41467-021-27424-z
9. Tamagno, S., A.J. Eagle, E.L. McLellan, C. van Kessel, B.A. Linquist, J.K. Ladha, and C.M. Pittelkow. (2022). Quantifying N leaching losses as a function of N balance: a path to sustainable food supply chains. *Agriculture, Ecosystems and Environment* doi.org/10.1016/j.agee.2021.107714
10. Perry, H., D. Carrijo, and B.A. Linquist (2022) Single midseason drainage events decrease global warming potential without sacrificing grain yield in flooded rice systems. *Field Crops Research*. doi.org/10.1016/j.fcr.2021.108312.
11. Linquist, B.A., J. Campbell, and R.J. Southard. (2022) Assessment of potassium availability and soil balances in high yielding rice systems. *Nutrient Cycling in Agroecosystems* 122:255-271. doi.org/10.1007/s10705-022-10200-w
12. Rosenberg, S., A. Crump, W. Brim-DeForest, B. Linquist, L. Espino, K. Al-Khatib, M.M. Leinfelder-Miles, C.M. Pittelkow. (2022) Assessing crop rotation feasibility for rice systems in California: Baseline assessment of barriers and opportunities. *Frontiers in Agronomy*. doi.org/10.3389/fagro.2022.806572
13. Tamagno, S., Eagle, A.J., McLellan, E.L., van Kessel, C., Linquist, B.A., Ladha, J.K., Lundy, M.E., and Pittelkow, C.M. (2022) Predicting nitrate leaching loss in temperate rainfed cereal crops: relative importance of management and environmental drivers. *Environmental Research Letters*. doi.org/10.1088/1748-9326/ac70ee.
14. Carrijo, D.R., G. LaHue, S. Parikh, R. Chaney, and B.A. Linquist. (2022) Mitigating the accumulation of arsenic and cadmium in rice (*Oryza sativa*) grain: a quantitative review of the role of water management. *Science of the Total Environment* doi.org/10.1016/j.scitotenv.2022.156245
15. Rehman, T., M. Lundy and B.A. Linquist. (2022) Comparative sensitivity of vegetative indices measured via proximal and aerial sensors for assessing N status and grain yield in rice cropping systems. *Remote Sensing* doi.org/10.3390/rs14122770

FACT SHEETS

In 2020, the UCCE Rice Specialist and Farm Advisors developed a series of Fact Sheets. These are two page handouts with “must-know” information on a particular topic. So far we have 10 Fact Sheets and are adding more regularly. They can be seen at http://rice.ucanr.edu/FactSheets/Rice/. I developed the following:

Fact Sheet 1: Nutrients in Rice Grain and Straw at Harvest
Fact Sheet 2: Managing Potassium in Rice Fields
Fact Sheet 5: Growing Season Water Use in California Rice Systems
Fact Sheet 6: Managing Rice with Limited Water
Fact Sheet 7: Managing Phosphorus in California Rice Fields
Fact Sheet 9: Optimal and Critical Nutrient Concentrations in Rice Tissue

PRESENTATIONS (2022)

Linquist, Bruce. 2022. Nutrient management in California rice systems. Rice winter grower meetings.
Linquist, Bruce. 2022. Year in Review and Yield Contest. Rice winter grower meetings.
Linquist, B. 2022. Optimizing rice production in fields that have been fallowed. Stop on field day tour. Rice Field Day August 31, 2022.
Godbey, M., B. Linquist, W. Brim-DeForest, and L. Espino. Exploring no-till systems in water seeded rice. Rice Field Day August 31, 2022.
Zhang, Z., D. Olk, and B. Linquist. Introduction of upland soil conditions alter yield potential in California rice. Rice Field Day August 31, 2022.
Zhang, Z., D. Olk, and B. Linquist. Introduction of aerobic soil conditions alter yield potential in California rice. Presentation at the ASA-CSSA-SSSA International Annual meetings. Nov 6-9, 2022, Baltimore, MD.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Objective 1. Impacts of fallow and crop rotation on N fertility management
We have studied rice production in rice after a fallow and after rice (continuous rice) for two years. In both years' yields were higher in fallowed rice compared to continuous rice. Why are yields higher in fallowed fields? For at least two reasons. First, higher yields after may be due to less disease as there was less stem rot in rice after fallow than after rice. Second, fertilizer N uptake was the same between treatments but the fallow had a greater late season N supply from the soil. From a management perspective, this suggests that less N needs to be applied – especially top-dress N in fields coming out of a fallow.

Objective 2. "No-till" planting into ground previously fallowed and worked ground
Growers have had to fallow rice fields due to drought. These fallowed fields are often worked during the fallow period to the point of being leveled. We studied if it was possible to simply flood up these fields the following season without any further tillage (NT). We tested this NT approach with conventional tillage (CT) in 3 commercial fields. We found the following. Stand establishment was poorer in NT fields. This was likely due to the windy conditions in May. Weed, pest and disease pressure were either similar or better in the NT treatments. Importantly, yields were either similar or higher in the NT treatments. These results are very encouraging and we hope to pursue this research next year.

Objective 3. Alternative N fertilizer management strategies

Alternative N management strategies are needed when aqua-ammonia (most common N source for CA farmers) is not able to be applied. We evaluated six products applied at different times. Some general findings focusing on the post-planting fertilizer applications are:
Some general findings are:

1. Aqua ammonia or urea applied to a dry soil before flooding resulted in the highest yields. This confirms other earlier findings we have made.
2. If a preflood application to a dry soil is not possible, the next best scenario is to split the N rate. The total N rate split at 15-35-35-15% at 3-4-5-6 weeks after planting will likely give the best results. However, the total N rate may need to be increased compared to aqua or urea applied before flooding.
3. Using enhanced efficiency fertilizers such as Super U, Agrotain or Agrocote, had no benefit over applying urea alone. These are expensive fertilizers.