ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
January 1, 2023- December 31, 2023

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

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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 2023 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) “No-till” drill seeding into soil moisture.

SUMMARY OF 2023 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1. Impacts of fallow on N fertility management
In California rice systems, increasingly we are seeing an increase in rice water sales, which leaves the soil fallow for a year. Farmers often report higher rice yields in rice following a fallow. 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. One reason for differences in N management 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. In 2021 and 2022, we found that phenols were higher in continuous rice fields compared to fields coming out of a fallow. In this third year of this study, we wanted to continue to look at the grain yield response to N in rice following a fallow vs rice following a previous rice crop. Thus the broad 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
2023 was the third year of this study. In 2023, we ran the experiment like we ran the 2021 and 2022 experiments. 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 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].

Soil samples were taken before planting for a background analysis of soils. When fields were drained in preparation for harvest, plant samples were taken to rate disease. At harvest, yields were determined with a small plot combine and plant samples were taken for N 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

In all years' yields were higher in fallowed rice compared to continuous rice, although this was only significant in 2021 (Fig. 1). In 2022 and 2023, 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 potentially 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. This is shown based on previously reported data, but is also seen in Figure 1 where we see higher yields in the fallow treatment where no fertilizer N was applied.

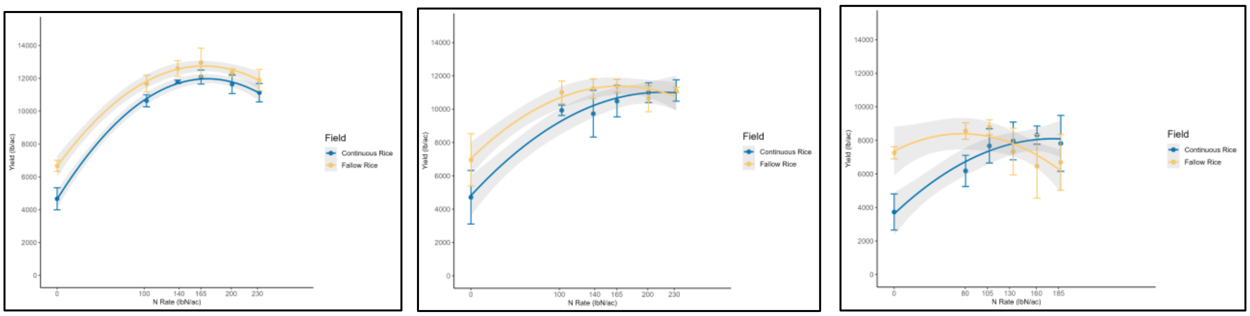


Figure 1. Rice yield in 2021 (left) and 2023 (right) in rice after fallow and continuous rice as affected by N rate.

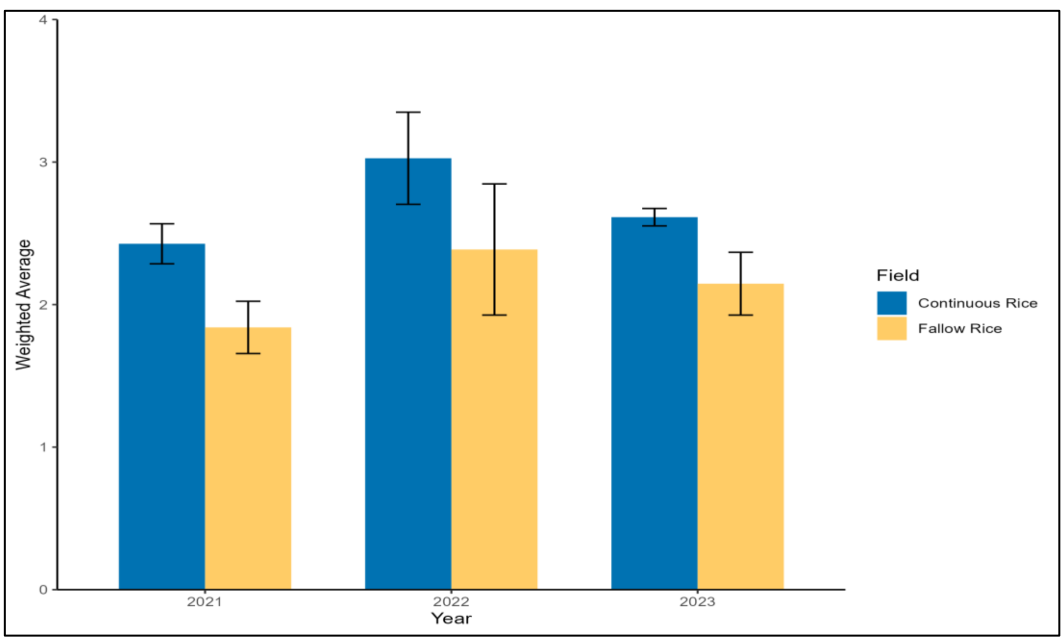


Figure 2. 2021 to 2023 stem rot severity scores of rice following rice or following a fallow.

Going forward
2023 was the last year of field research for this study. In 2024, we plan to finish up the plant analysis and other data analysis for this study.

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

Background

In four of the past nine 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. This is effectively a seedbed. If this ground is planted in the following year, without further tillage, it is considered a stale seedbed.

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 stale seedbed "no-till" (SS-NT) (72.6 cwt/ac). This was followed up with promising results in 2022 with more rigorous on-farm studies. Given the 2022 promising results, in 2023, we continued with the on-farm studies and at the RES.

Methods

In 2023, we conducted a study at three on-farm sites (similar to 2022). For the on-farm study, we asked farmers who were going into a fallowed field with a stale seedbed (land worked previous year) to leave out one acre without tillage. Thus, for each grower, there was a stale seedbed no-till (SSNT) treatment and the conventional tillage (CT) treatment which was the normal practice of tillage and planting. For the SSNT 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 SSNT 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. A weed assessment was taken mid-season to quantify weeds in both SSNT 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.

At the RES, a more controlled and replicated study was conducted. The study was replicated 3 times. It was set up as a split-plot design with main plots being SSNT and CT. Subplots were N treatments. All N plots were harvested with a small plot combine harvester.

Results

The results can be summarized as follows:

Stand establishment: Across both years of the on-farm studies, stand establishment was lower in the SSNT at five of the six sites (Fig 4). We feel that this was largely due to wind following planting. Ideally, there should be at least 12 plants/ft2 for optimal yields. This was achieved at most locations – but not all. Based on this, our recommendation would be to roll the field in the fallow year to established groves for the seedlings to fall into. Also, using a Leather's practice would also help establish seedlings.

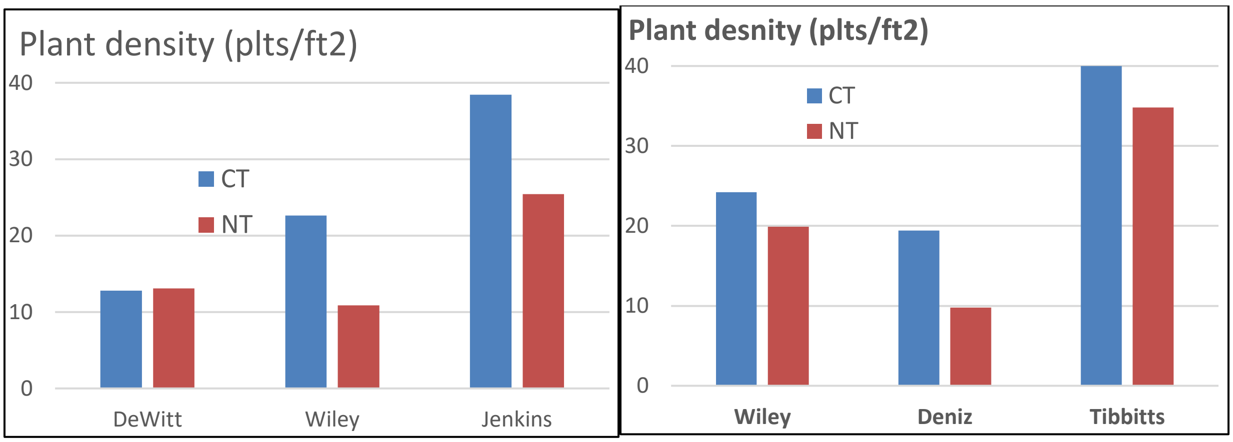
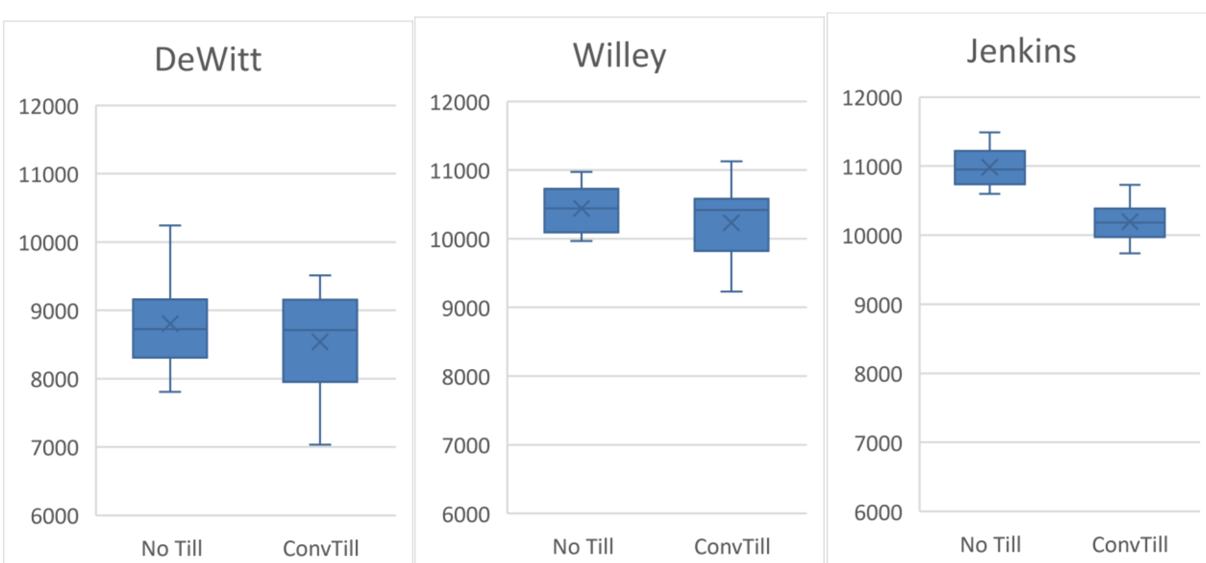


Figure 4. Plant density about 2-3 weeks after planting in stale seedbed no-till (NT) and conventional till (CT) treatments.

Yields: Yields were similar to higher in the NT treatment (Fig. 5). In the large 3000 ft2 plot where we took multiple combine harvests to get an average yield and a yield variation, we saw yields and variability were similar. In 2022, yields in the SSNT at Jenkins was higher. In 2023, yields in the SSNT at Deniz was lower.



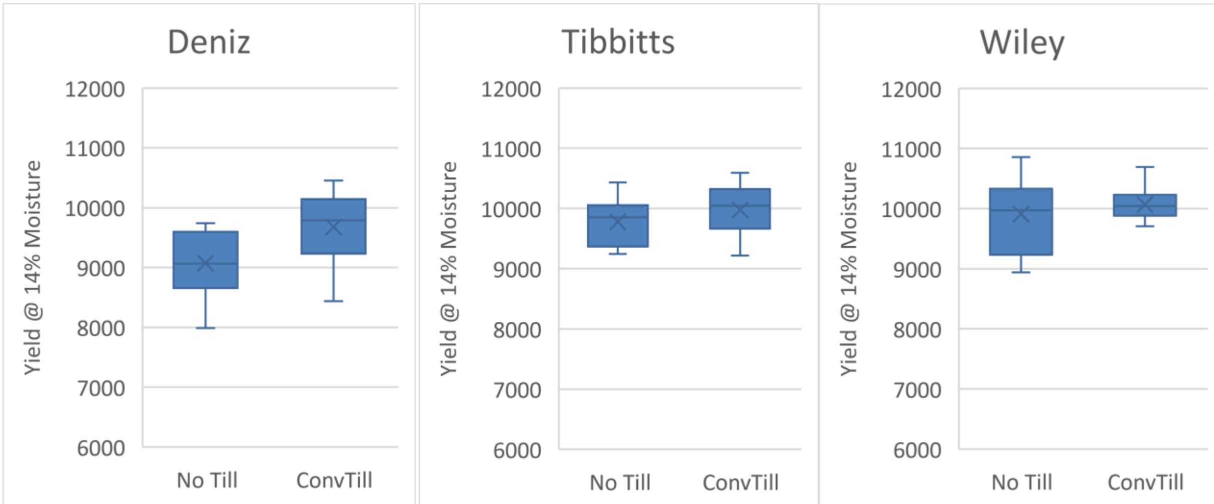
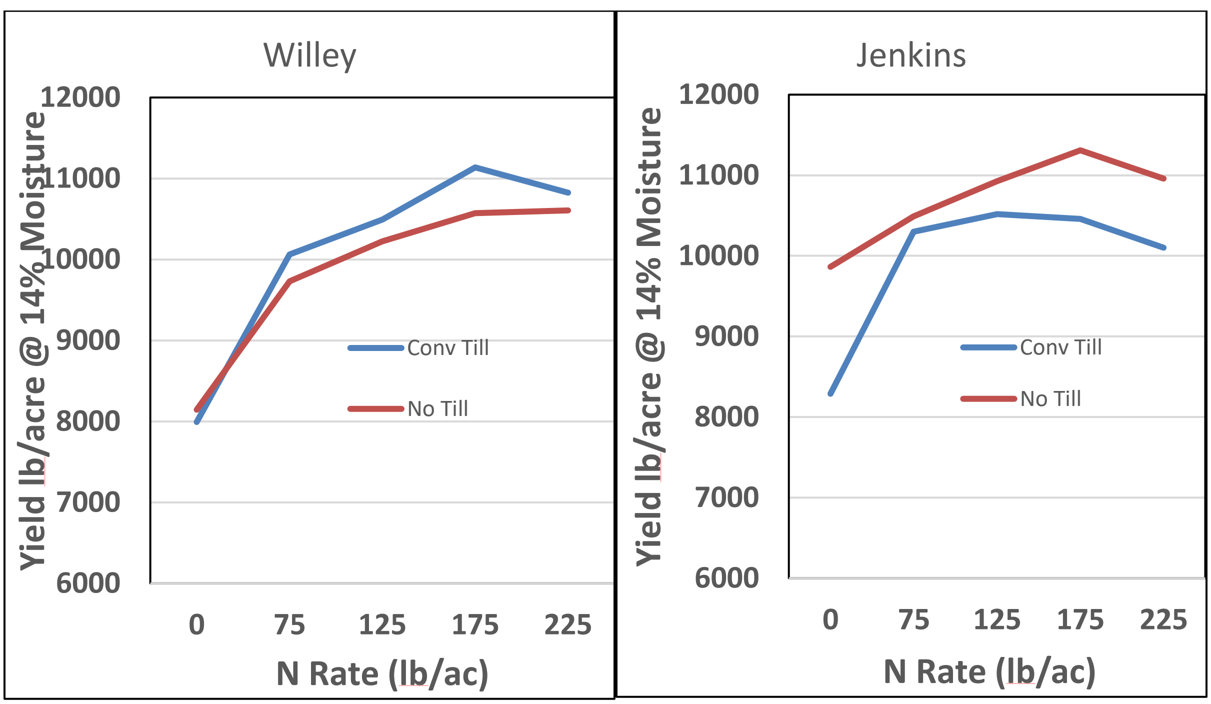


Figure 5. Yield and yield variability between stale seedbed no-till (NT) and conventional till (CT) at three locations. The yield average and variability were taken from 14 small plot combine harvests (150 ft^2 each). The top row is 2022 and bottom row is 2023.

Response to N: The data on yield response to N fertilizer was only good for two sites in each year. At one location (DeWitt), the water drained from the field too soon which confounded the N trail data. At Deniz site in 2023, issues with stand establishment prevented an analysis of the data.

At most locations, the N rate required to reach optima yields was similar in the SSNT and CT and was usually at 175 lb N/ac (Fig. 6).



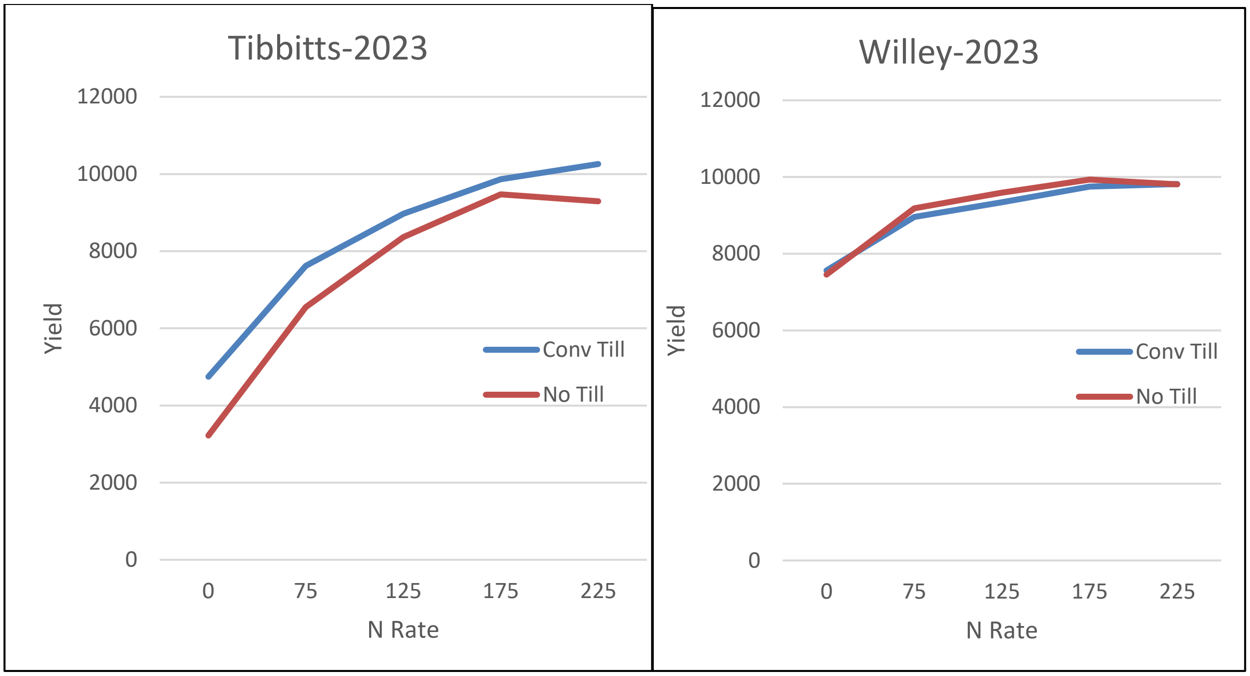


Figure 6. Yield response to N in stale seedbed no-till (NT) and conventional till (CT) treatments. The top row is 2022 and bottom row is 2023.

At the RES, maximum yields were comparable between the SSNT and CT (green and red lines respectively in Fig. 7). Optimal yields were achieved at 90 lb N/ac in the CT and 120 lb N/ac in the SSNT. Figure 7 includes the N response in a continuous rice system (blue line-from objective 1 above). What is apparent in this study as with Objective 1, is that there is more N in the fields where it was fallow the previous year. This is seen by higher yields in the SSNT and CT when no N fertilizer is applied.

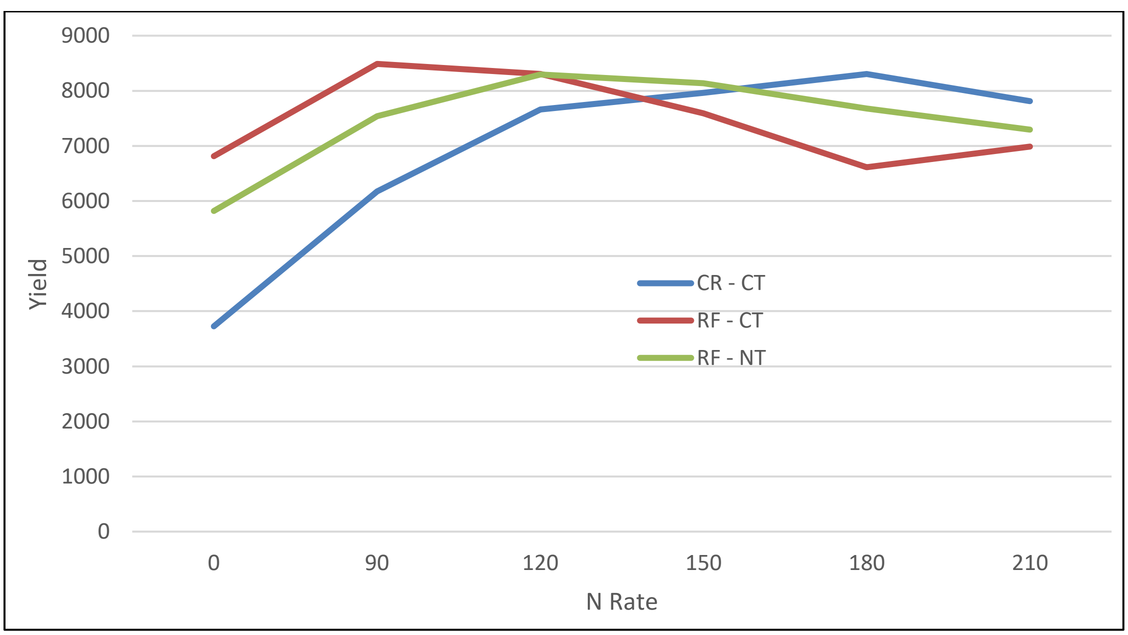


Figure 7. Yield response to N fertilizer in stale seedbed NT (RF-CT), and conventional till in rice following a fallow (RF-CT) and rice following rice (CR-CT).

In Summary

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

- 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 weed control stale seedbed. In season 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 in which the seedbed is prepared the year before, allows growers to flood as soon as temperatures are high enough to germinate weeds seeds.

Going forward

We do not plan further field work in this area. Some growers have expressed interest and we may work with them to scale this up.

Objective 3. "No-till" drill seeding
Background

Drought and limited water may be the biggest threat to the sustainability of rice systems in California. We have examined some practices to reduce water use in CA rice systems such as shorter duration varieties and planting later in season – both of which reduce water use by about 1 inch. Practices are needed that have a much larger reduction on water use.

One practice that may work in California is no-till (NT) planting. No-till planting is not a new practice and is used commonly to conserve moisture in other crops. In rice it has also been shown to be possible and is practiced by farmers in the mid-south. No-till could be practiced into a stale seedbed (ground worked and seedbed prepared in the previous season) or into a field that had had rice the previous season and the field is free of ruts.

How much water could be saved compared to a conventional water seeded system? Right now, fields are tilled starting in late March and early April to dry out soil to prepare a nice dry seedbed. This water could instead be used to start a rice crop. Only looking at evapo-transpiration (ET) in the first month of the season, one could achieve 6 to 7 inches of water savings. During the first month, ET in rice systems is about 6.6 inches. This is calculated by multiplying the reference ET (5 mm/day or 0.22 inches/day) by the crop coefficient (1.1) by the number of days. During the first month of the season, most of the water losses from water seeded rice are from evaporation (E). The transpiration (T) component is very small.

The benefits of no-till include saving water, early planting, no additional tillage costs, likely less weed pressure, and any rainfall during Apr and May and before a permanent flood is beneficial. There are also potential challenges which include equipment costs, getting heavy clay soils to close around the seed, and identifying the optimal planting time to take advantage of soil moisture without rutting up the field. This practice also will not work if the field was left heavily rutted up from the previous season.

In 2023, we did pilot study to test the promise of no-till drill seeded systems.

Methods

We will examine NT planting into moisture at the RES in 2023. We will examined it on four different systems (each replicated three times) varying in previous straw management:

1. Stale-seedbed: Previous year was fallow and fields were well worked and leveled
2. Previous years straw burned
3. Previous years straw was bailed
4. Previous years straw was chopped.

The above treatments will likely have large effects on how fast the soil dries; however, since some of the treatments were in the same basin, the planting date was the same for all of them (May 2). All seed (variety M-206) was planted with seed that is treated with gibberellic acid to promote gemination and seedling elongation. We monitored soil moisture from planting to stand establishment and yields. Included in the trial will also be an N rate trial with N rates ranging from 0-225 lb N/ac). A treatment with manure was also included. The N fertilizer (urea) and manure was all applied just before the permanent flood on June 2. There were no flushes of water between the initial flush at planting and the permanent flood.

Two herbicide programs were tested.

- Prowl at planting
- Prowl, Clincher and Propanil applied just before a permanent flood.

Plants were assessed for disease when the fields were drained in preparation for harvest. At harvest, all plots were harvested with a small plot combine to determine yield.

Results

Soil Moisture: At planting there was more soil in the top 6 inches in the chopped treatment than where rice was fallow or where straw was burned (Fig. 8). Just before flooding for the permanent flood, soil moisture was also a bit higher in the chopped treatment compared to the others.

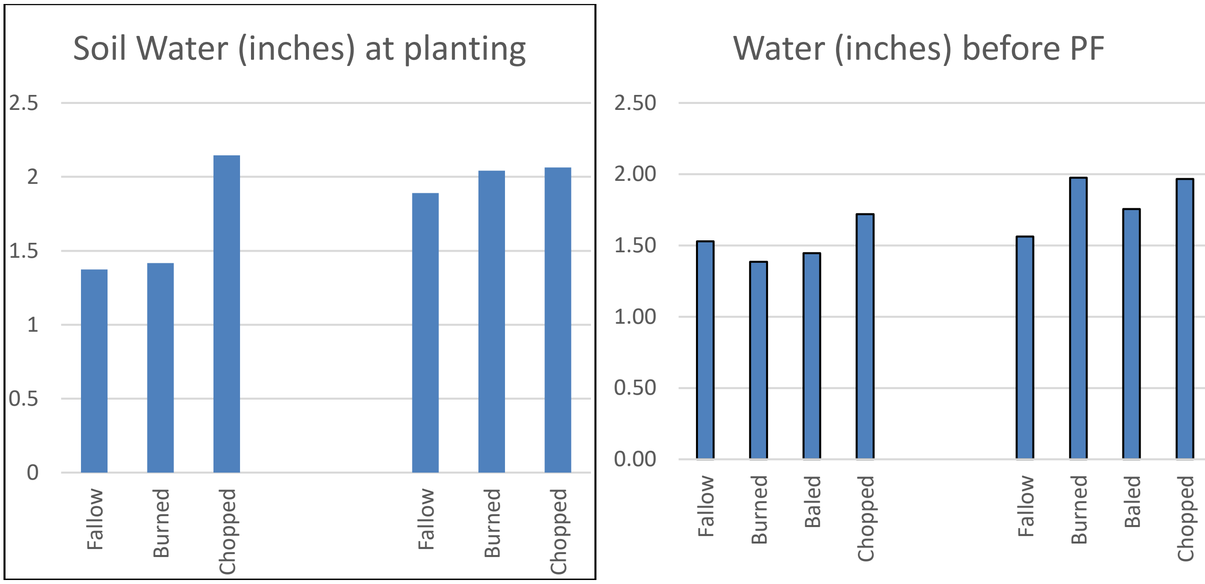


Figure 8. Gravimetric soil water content at planting and just before a permanent flood (PF). In each figure the left-hand side is 0-6 inches and the right-hand side is 6-12 inches.

Weed control:

- Without any herbicides, the chopped treatment had very few weeds except for sprangle top. The fallow, burned and baled treatments all had a significant amount of other weeds including broadleaf, sedges and grasses.
- Prowl at planting: Provided good control in all treatments except the burned.
- Prowl, Clincher and Propanil applied just before a permanent flood: Provided good control across all treatments.

Yields: Yields responded to N fertilizer. In all cases, the maximum grain yields were achieved at about 175 lb N/ac. Maximum yields were seen in the fallow treatment where yields of roughly 8600 lb/ac were obtained. Yields in the other treatments were lower (7600-8300 lb/ac). In the fallow treatment, there was a good response to manure, with yields of 8800 lb/ac; however, yields in the other treatments were a lot lower (7500 lb/ac or lower).

While these yields are low, they are comparable to the water-seeded conventional yields we achieved at the RES this year. In Figure 7, the highest yields achieved were 8500 lb/ac. It is not clear why overall yield potential was lower at the RES this year. That said, these data indicate that the yield potential in these no-till systems are comparable to conventional water seeded systems.

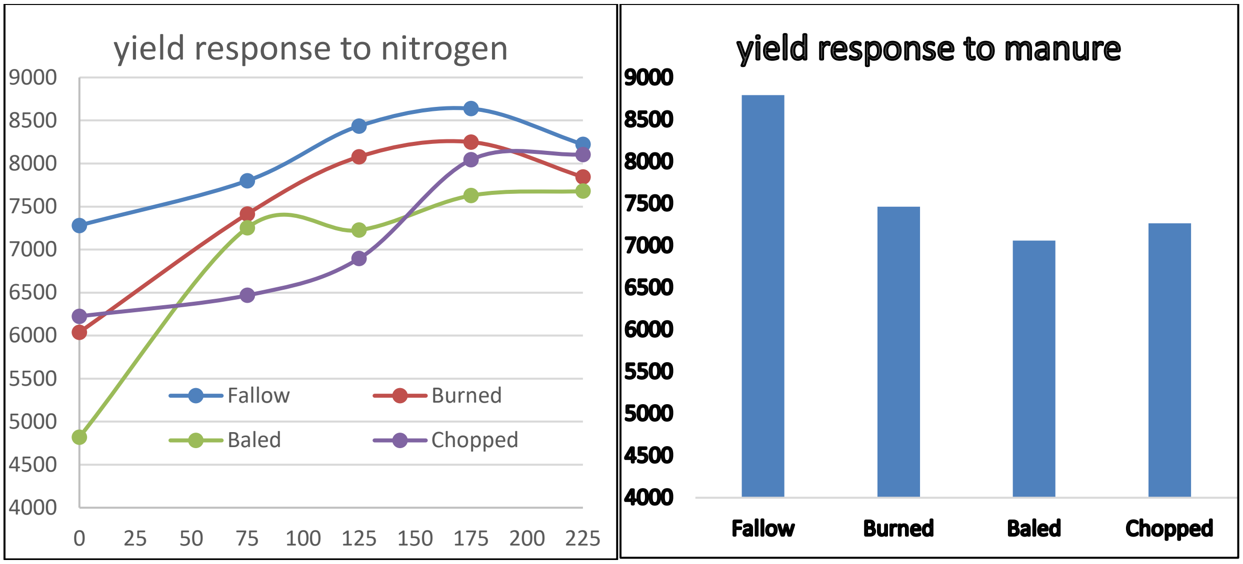


Figure 9. Grain yield response to nitrogen fertilizer and manure.

Going forward
We are very encouraged by these results and plan to continue this research on 2024 with replicated experiments.

PUBLICATIONS OR REPORTS:

PUBLICATIONS (Rice publications 2021-23):

1. 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
2. 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.
3. 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
4. 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.
5. 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
6. 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
7. 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
8. 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
9. Rehman, T., M. Lundy, A. Froes de Borja Reis, N. Akbar, and B.A. Linquist. (2023) Reflectance measurements from aerial and proximal sensors provide similar precision in predicting the rice yield response to mid-season N applications. *Sensors* doi.org/10.3390/s23136218
10. Cornelio, K. and Linquist B.A. (2023) Assessing fertilizer nitrogen sources and application timing for water-seeded rice systems. *Agrosystems, Geosciences & Environment*. doi: 10.1002/agg2.20415
11. Linquist, B.A. and H. Perry (2023) Greenhouse gas emissions and grain arsenic concentrations as affected by a weed control drainage in organic rice systems. *Agrosystems, Geosciences & Environment*. doi:10.1002/agg2.20417
12. Qian H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R., Minamikawa, K., Martinez-Eixarch, M., Yan, X., Zhou, F., Ole Sander, B., Zhang, W., Shang, Z., Zou, J., Zheng, X., Li, G., Liu, Z., Wang, S., Ding, Y., van Groenigen, J.K., Jiang, Y. (2024) Greenhouse gas emissions and mitigation in rice agriculture. *Nature Reviews Earth & Environment*. doi.org/10.1038/s43017-023-00482-1
13. Salvato, L., Pittelkow, C., O'Geen, T. and Linquist, B.A. (2024) A geospatial assessment of soil properties to identify the potential for crop rotation in rice systems. *Agriculture, Ecosystems and Environment* doi.org/10.1016/j.agee.2023.108753.

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 16 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
Fact Sheet 15: Managing Water Salinity in Rice Fields
Fact Sheet 16: Assessing Need for Top-Dress N in Rice Using a Sufficiency Index

PRESENTATIONS (2023)

Linquist, Bruce. 2023. Nutrient management in California rice systems. Rice winter grower meetings.
Linquist, Bruce. 2023. Year in Review.
Linquist, B. 2023. Optimizing rice production in fields that have been fallowed. Stop on field day tour. Rice Field Day August 30, 2022.
Godbey, M., B. Linquist, W. Brim-DeForest, and L. Espino. No-till rice systems as an alternative to conventionally managed rice. Rice Field Day August 30, 2023.
Zhang, Z., D. Olk, and B. Linquist. Introduction of aerobic soil conditions to continuous rice enhances nitrogen availability. Rice Field Day August 30, 2023.

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 three years. In general, yields were higher in rice following a fallow compared to continuous rice. Higher yields after may be due to less disease as there was less stem rot in rice after fallow than after rice. This may be partly rectified by applying a fungicide. Importantly, following a fallow, there is more soil nitrogen available to the crop. This means that the N rate should be reduced in rice after fallow compared to continues rice.

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 (stale seedbed - NT). This practice is technically called a "stale seedbed" because the seedbed was prepared in the previous year. We tested this NT approach with conventional tillage (CT) in 3 commercial fields in each of 2022 and 2023. We also studied this in a replicated field trial at the RES in 2023. We found the following. Stand establishment was poorer in NT fields. This was likely due to the windy conditions in May. This could be rectified with higher seed rates, using a Leather's method and ending up the previous year's tillage operation with a roller. Weed, pest and disease pressure were either similar or better in the NT treatments. Importantly, yields were similar in the NT treatments. These results are encouraging and would allow a grower to plant earlier in the season.

Objective 3. "No-till" drill seeding
No-till drill seeding allows growers to plant early and conserve water. We examined no-till drill seeding into four seedbeds: a stale seedbed (ground was fallowed and worked to a seedbed the previous year), and no-till into fields where previous years straw was either chopped, baled or burned (all were winter flooded). Yields responded to N fertilizer. In all cases, the maximum grain yields were achieved at about 175 lb N/ac. Maximum yields were seen in the fallow treatment where yields of roughly 8600 lb/ac were obtained which were similar to conventional till yields. Yields in the other treatments were lower (7600-8300 lb/ac). In the fallow treatment, there was a good response to manure, with yields of 8800 lb/ac; however, yields in the other treatments were lower (7500 lb/ac or lower). In the chopped treatment, the straw layer provided a

high level of natural weed control. We plan to continue this work to develop optimized N management, weed control and to quantify water savings.