ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
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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 2019 the following specific objectives will be addressed.

1) Assessing top-dress N needs through remote sensing using GreenSeeker and drones
2) Potential N losses early in the season due to flooding/draining events
3) Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

SUMMARY OF 2019 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1. Assessing top-dress N needs through the use of remote sensing

Overview

This study was initiated in 2015 to evaluate the potential of sensor-based technologies to access N status in rice and determine the need for top-dress applications. Based on our studies thus far, we have found that NDVI measured with a GreenSeeker at PI is a strong predictor of crop N uptake and final grain yield (Rehman et al. 2019). One limitation of GreenSeeker NDVI is that NDVI values plateau (saturate) at high levels of crop N uptake, thus making it difficult to identify differences between fields. However, data collected with the drone during the 2018 growing season demonstrated that NDRE was also a strong predictor of crop N uptake but did not plateau at high crop N uptake values like NDVI does. In 2019, our objectives were, first, confirm that NDRE does not plateau as we have seen with NDVI (this has only been tested in 2018 and more data is required). Secondly, in order to guide midseason top dress management, NDVI and NDRE response indexes were developed to predict the grain yield response to top dress N fertilizer across the range of index values. Once completed, the products of this research will provide farmers a robust decision support tool to guide them in their mid-season N fertilizer management.

Methodology 2019

Nitrogen rate trials were conducted at three on-farm and one on-station site throughout the Sacramento Valley. In all cases the variety M-206 was used. The experiments were arranged according to a randomized complete block design. The main plot treatment was preplant N injected into the soil as aqua ammonia at rates ranging from 0-210 lbs ac^{-1}. At PI, NDRE was measured using the drone and NDVI was measured with both the drone and GreenSeeker. After index measurements, plant samples were collected from each plot and the plots were split into subplots receiving top dress fertilizer at rates of either 0 or 30 lbs N ac^{-1}. Finally, soil samples were collected from the 0 and 150 N plots. At heading, plant and soil samples were again collected from the 0 and 150 N plots. At maturity, rice plants were harvested from each subplot to measure yield.

The following specific measurements were taken at each site:

Soil at each location at start of season were analyzed for total N, organic C, pH, and texture

1. At PI
    a. aboveground biomass from each N plot was analyzed for weight, N concentration and total N uptake.
    b. Green Seeker NDVI
    c. Drone flying with a multispectral camera to collect NDVI and NDRE (a new index identified to be more effective than NDVI by recent studies).
    d. Soil from 0 and 150 N plots was analyzed for ammonium, nitrate, and phenolic carbon compounds
2. At Heading
    a. Aboveground biomass from 0 and 150 N plots was analyzed for weight, N concentration and total N uptake.
    b. Soil from 0 and 150 N plots was analyzed for ammonium, nitrate, and phenolic carbon compounds
3. At Harvest
    a. Above ground biomass and yield. Samples were analyzed for weight, N concentration and total N uptake.

Results

Our first objective was to quantify the relationship between PI crop N status and NDRE (drone) and NDVI (GreenSeeker and drone) taken at PI. Data from both 2018 and 2019 are present in the Figures below. NDVI from both the drone and GreenSeeker plateau at higher N rates. The NDVI from the Drone has higher values but plateaus at even lower crop N uptake values (Figure 1) making it a less reliable estimate of crop N status than the GreenSeeker.

However, comparing the NDVI and NDRE from the drone shows that the NDRE response to crop N uptake is linear across a wide range of crop N values. This confirms what we saw in 2018 as well as what others have seen for other crops. This suggests that for accessing crop N status and the need for applying mid-season N, the NDRE may be a better option than NDVI taken either from a drone or a GreenSeeker.

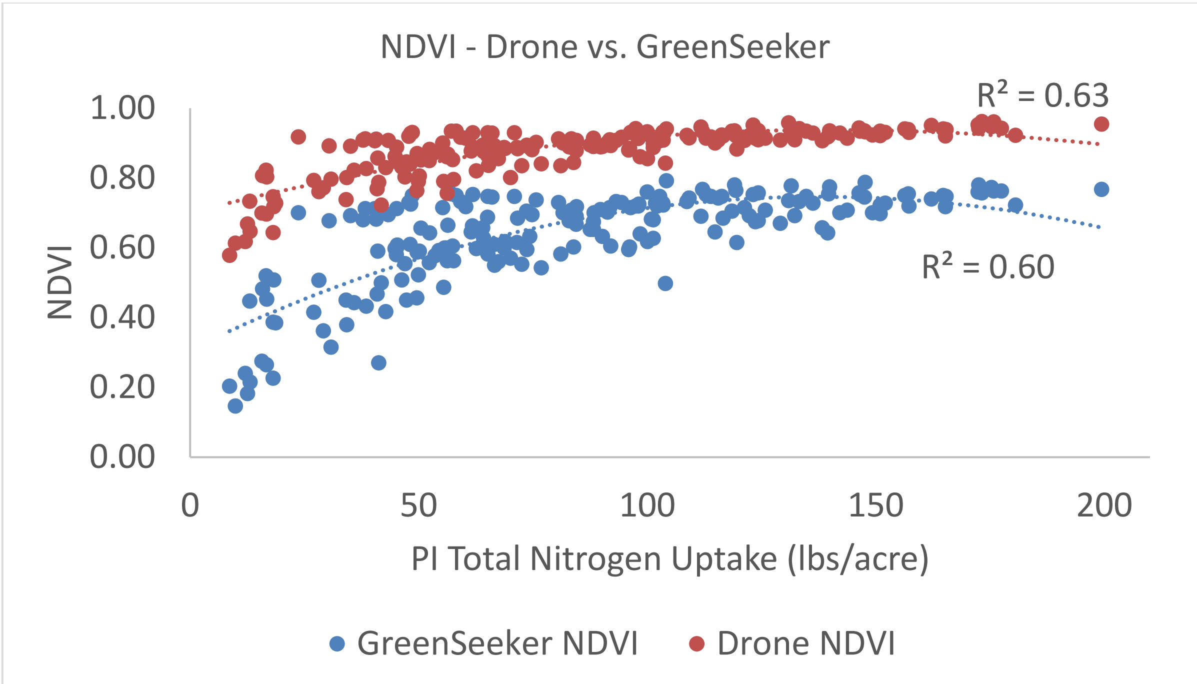


Figure 1. The relationship between PI total N uptake and NDVI measured with a drone and GreenSeeker. Data is from 8 sites established throughout the Sacramento Valley during the 2018 and 2019 growing season.

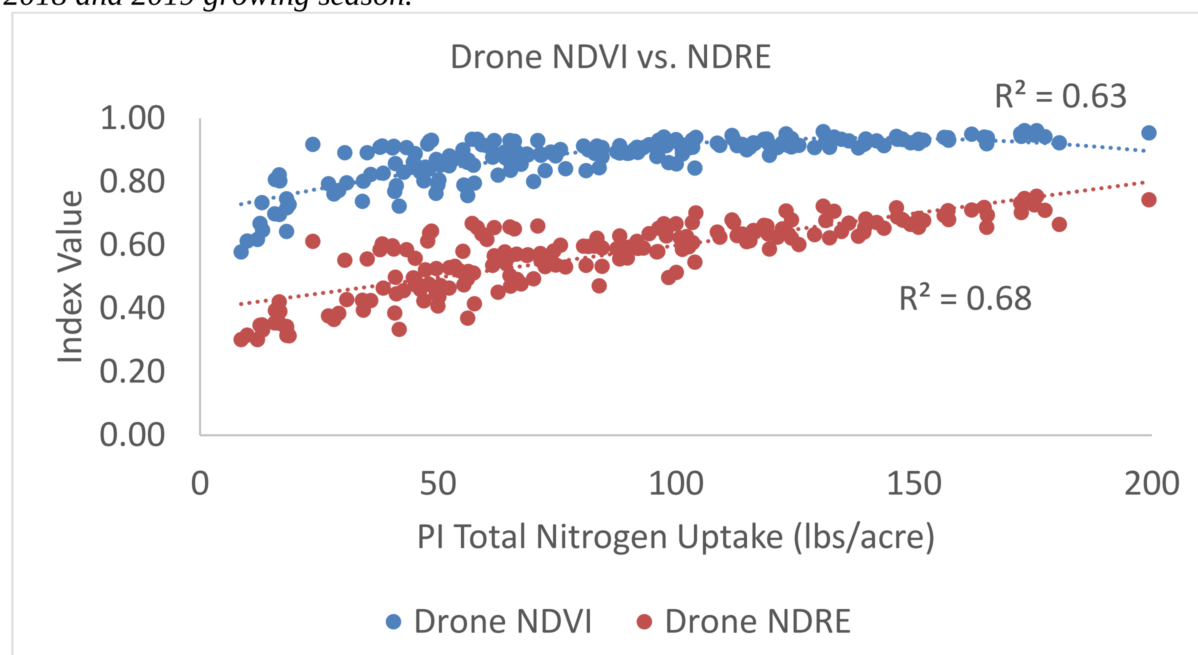


Figure 2. The relationship between PI total N uptake and NDVI and NDRE measured with a drone. Data is from 8 sites established throughout the Sacramento Valley during the 2018 and 2019 growing season.

A Response Index was developed at each experimental site using the following formula:

Response Index = NDVI (or NDRE) in N excess plot / NDVI (or NDRE) in treatment plot

Combining results from 2016 to 2019, we then examined the yield response to a topdress N application in each plot. We found that at an NDVI Response Index below 1.1, the average yield response was close to zero or negative and the likelihood of a positive yield response was 53% or less. When the Response Index was higher than 1.1 there was a positive yield response and a greater chance of a positive yield response (Figure 3 and 4).

Combining results from 2018 and 2019 an NDRE Response Index, we also found that when the Response Index was 1.1 or below, yields did not respond to top-dress applications and the chance of seeing a positive yield response was only 44% (Figure 5 and 6).

These data suggest that the GreenSeeker NDVI and drone NDRE are both useful tools in determining the need for a top-dress N application. When a top-dress was needed and applied, yields increased by roughly 200 to 1000 lb/ac.

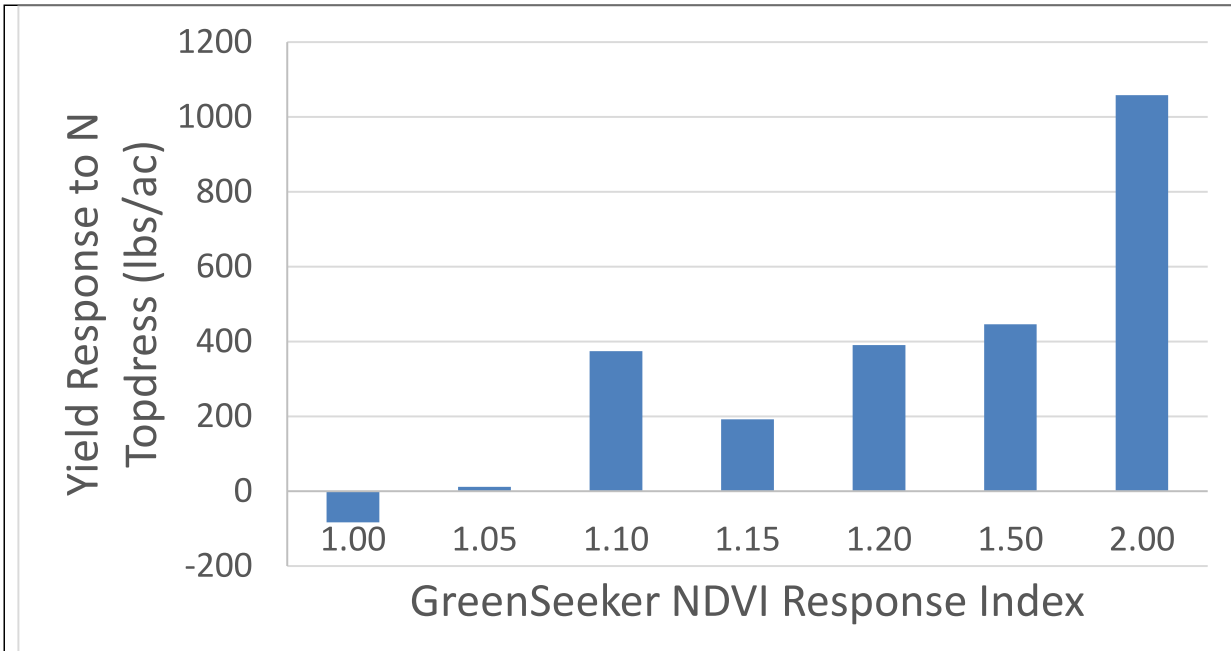


Figure 3. The relationship between average yield response to top dress N fertilizer applied at PI and GreenSeeker NDVI Response Index. Data was collected from 12 sites across the Sacramento Valley during the 2016 to 2019 growing seasons.

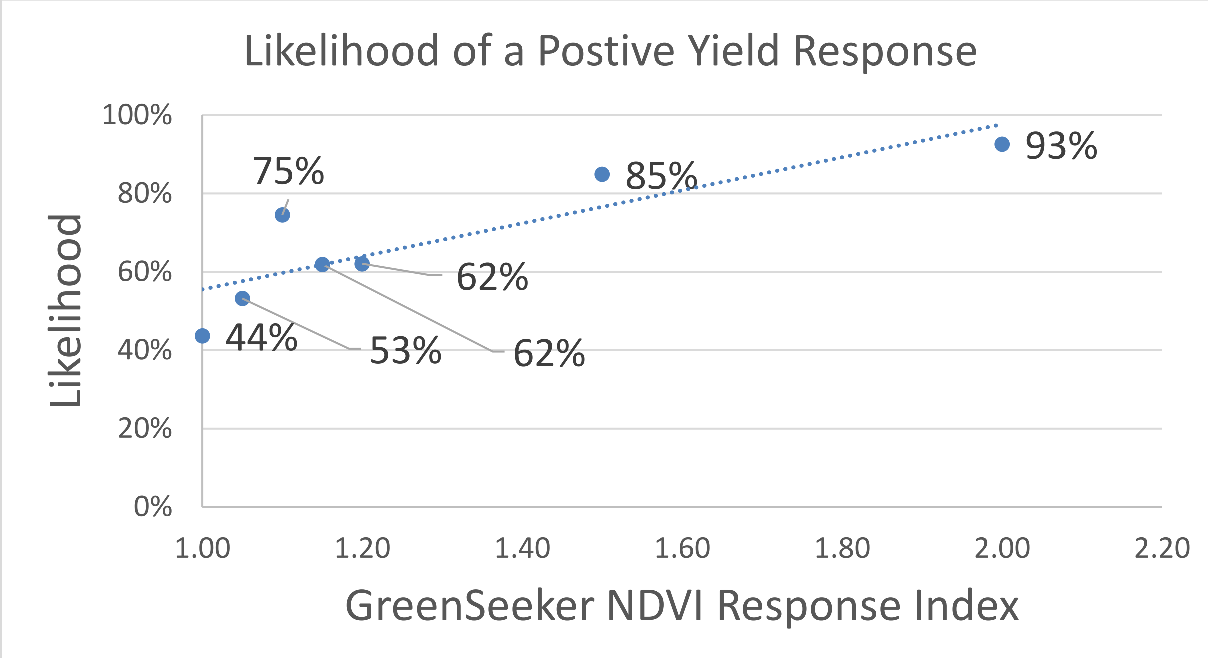


Figure 4. The likelihood (percent chance) of realizing a positive yield response to top dress N fertilizer across the range of GreenSeeker NDVI Response Index values. Data was collected from 12 sites across the Sacramento Valley during the 2016 to 2019 growing seasons.

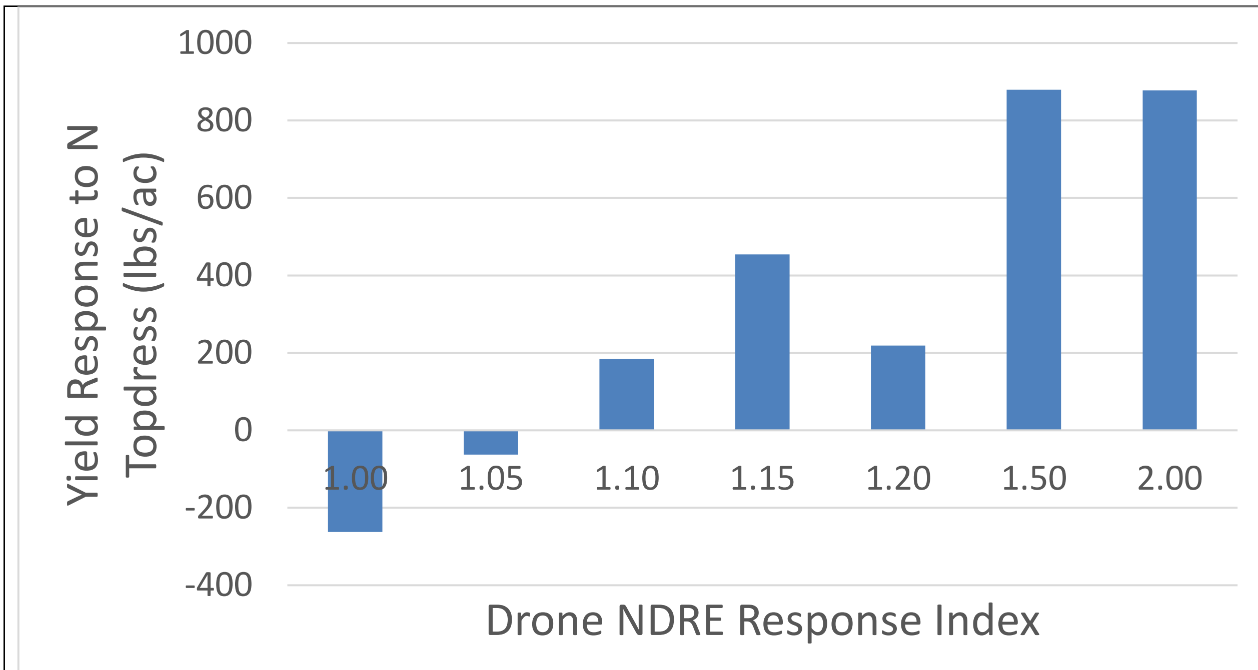


Figure 5. The relationship between average yield response to top dress N fertilizer applied at PI and drone NDRE Response Index. Data was collected from 8 sites across the Sacramento Valley during the 2018 and 2019 growing seasons.

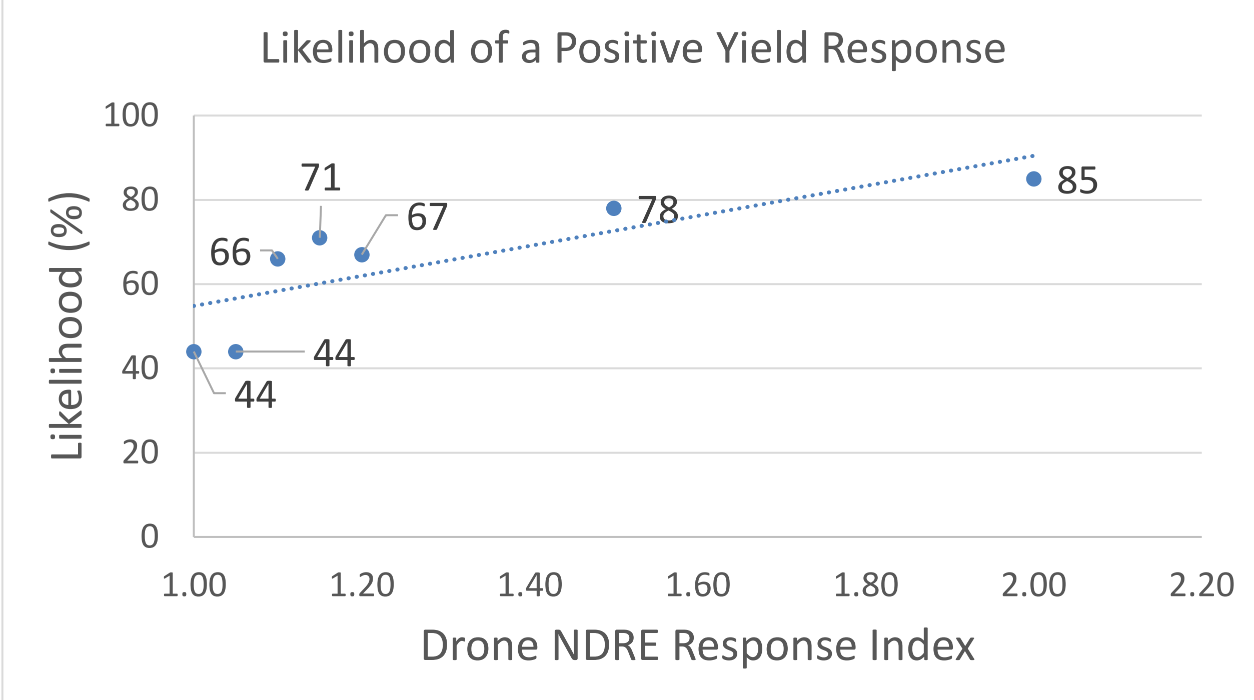


Figure 6. The likelihood (percent chance) of realizing a positive yield response to top dress N fertilizer across the range of drone NDRE Response Index values. Data was collected from 8 sites across the Sacramento Valley during the 2018 and 2019 growing seasons.

Objective 2. Potential N losses early in the season due to flooding/draining events

Background
This is a new study but it relates to questions I am often asked by growers. For example:

1. *I applied my fertilizer and flooded my field to plant, however, a levee broke and I lost all the water in my field. How much N have I lost?*
2. *I applied my aqua and then it rained and I could not get the roller on the field, so my flood data has been delayed by a week. How much N fertilizer have I lost?*
3. *I am drill seeding and I applied aqua before drill seeding. I then flooded and drained my field. I came along with a permanent flood at 4 weeks. Did I lose any N fertilizer from this practice?*
4. *I would like to practice a stale seedbed to control my herbicide resistant weeds. However, I want to apply my N as aqua before I do the stale seed-bed flush. Will my N fertilizer still be available for the crop?*

These are all excellent questions to which we do not have a solid answer. In conventionally managed rice fields, the fields are flooded shortly after aqua N is applied. Flooding protects the aqua N fertilizer from converting to nitrate (NO_3) because the field is anaerobic. This practice results in good N use efficiency. However, when we drain a field that still has a lot of aqua N in the soil, we introduce oxygen. That oxygen also microbes to convert the ammonium (NH_4) to NO_3 through a process called nitrification. When the field is reflooded, if the plant have not taken up the NO_3 (likely have not as early in season the plants take up very little N), the NO_3

denitrifies. That is it is lost as N_2 gas to the atmosphere. This is not a problem gas (such as a greenhouse gas) but it is a loss of N fertilizer.

We know well that this process occurs. What we do not know is how fast it occurs. Particularly, how fast nitrification (NH_4 to NO_3) occurs. The process will be driven by how aerobic (dry) the soils get during the dry down period, soil temperatures and some soil properties such as texture and carbon content.

Therefore the objective of this study is to determine how fast this conversion of NH_4 to NO_3 takes under different soils and drying conditions. With this information, we can help growers who have the questions raised above, to have a better idea of how much N is still available in the soil so that they can make more informed management decisions.

Methodology

This study was conducted in two field studies: at the RES and on a dry seeded fields near Knights Landing. We had two treatments:

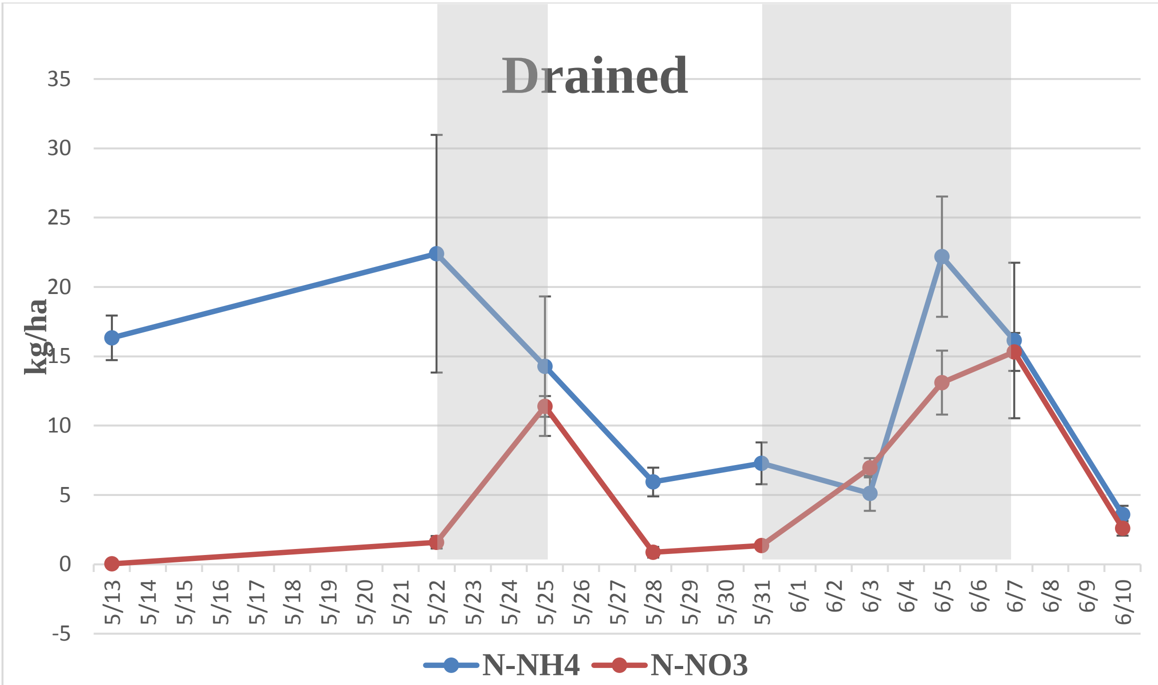
1. Aqua-N (maintained flooded)
2. Aqua-N (drained)

Treatments were replicated 4 times. In these studies we will kept the “flooded” treatments, flooded using rings to maintain a flood height. In the drained treatments, the field was under typical management for a dry seeded field. That is, after seeding the fields were flushed twice (7-10 day drying period between flushes) until a permanent flood was established after the stand was established. Soil samples in all treatments will taken from before flooding and N application through the drain periods and until a week after permanent flooding. All soil samples were analyzed for NH_4 and NO_3 to monitor the changes that took place during the establishment period. In addition, in all treatments we quantified soil moisture and temperature. Soil samples from each field will be taken to determine texture, organic C and N, pH, and EC.

For these studies (and additional laboratory studies) we will develop relationships between nitrification rates and how long the soil was dried down for, how dry the soil got, and various soil properties. From this data, we will be able to determine how much N is lost when soils are reflooded following a dry down event. This information will be able to guide growers to make better informed decisions on their N management.

Results

At the Knights Landing location N was applied at a rate of 80 lb N/ac as anhydrous-ammonium. At the RES is was applied at a rate of 150 lb N/ac as aqua-ammonia. There should not be a difference in results based on the application of anhydrous- vs aqua-ammonia. Data showing the soil NH4 and NO3 for each site are shown in Figures 1 and 2.



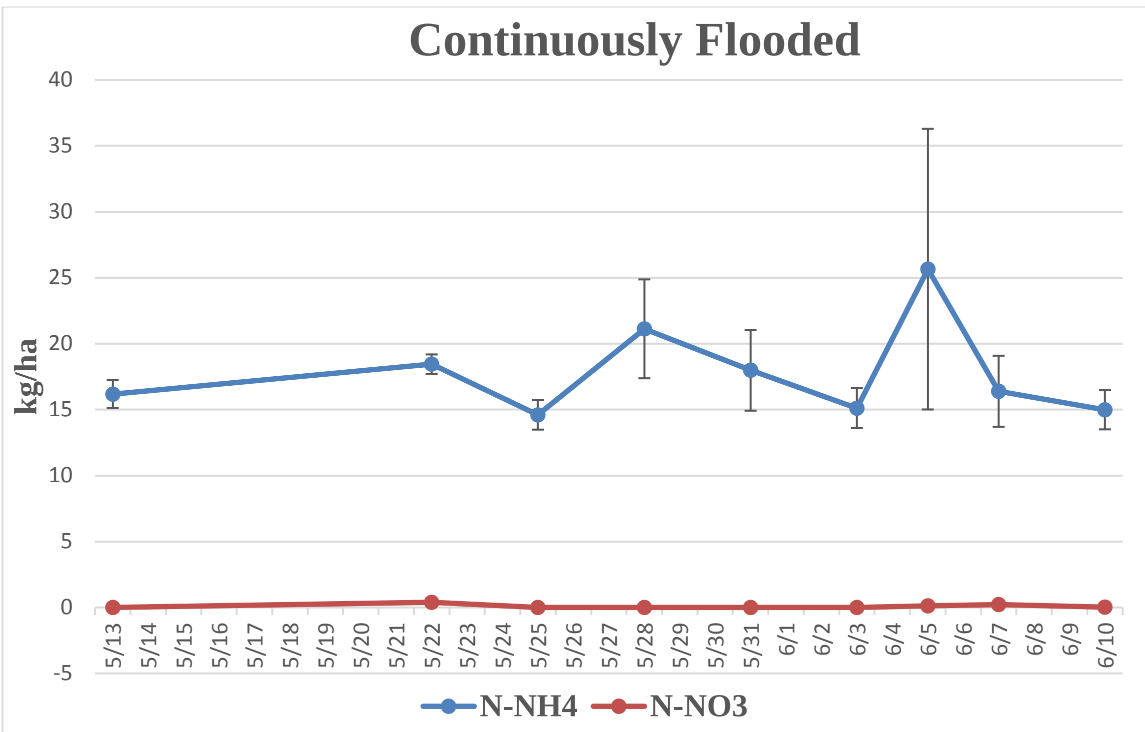
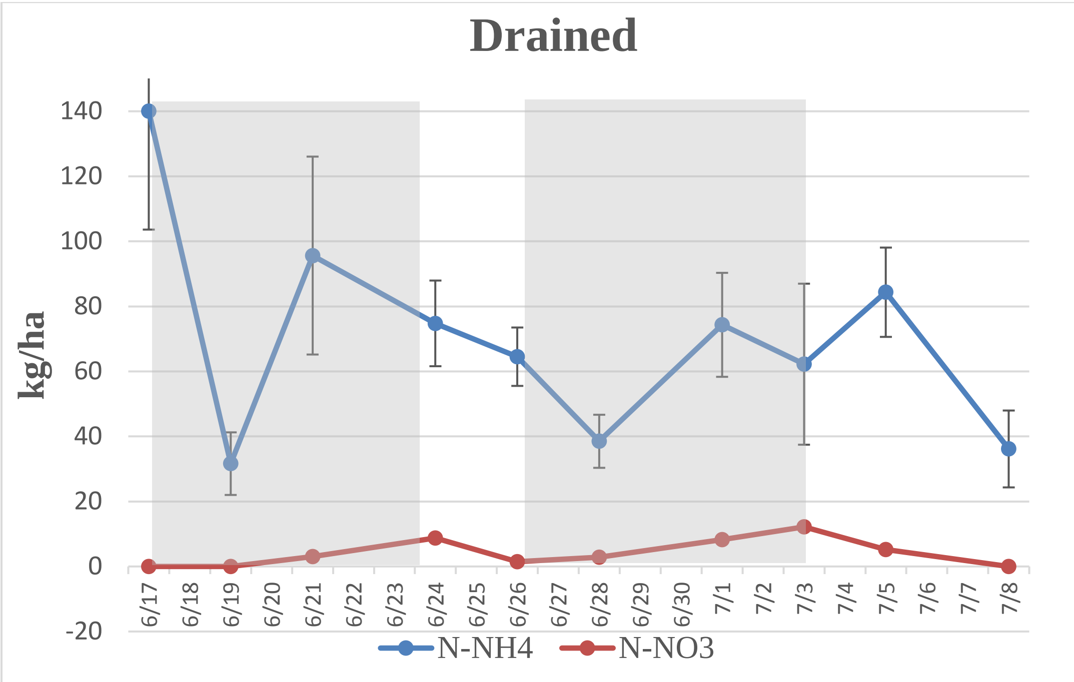


Figure 1. Soil extractable mineral N (NO_3 and NH_4) at the Knights Landing site. Data are for treatments that were continuously flood (top) and those that were periodically drained for crop establishment (bottom). Shaded area indicates drying periods.



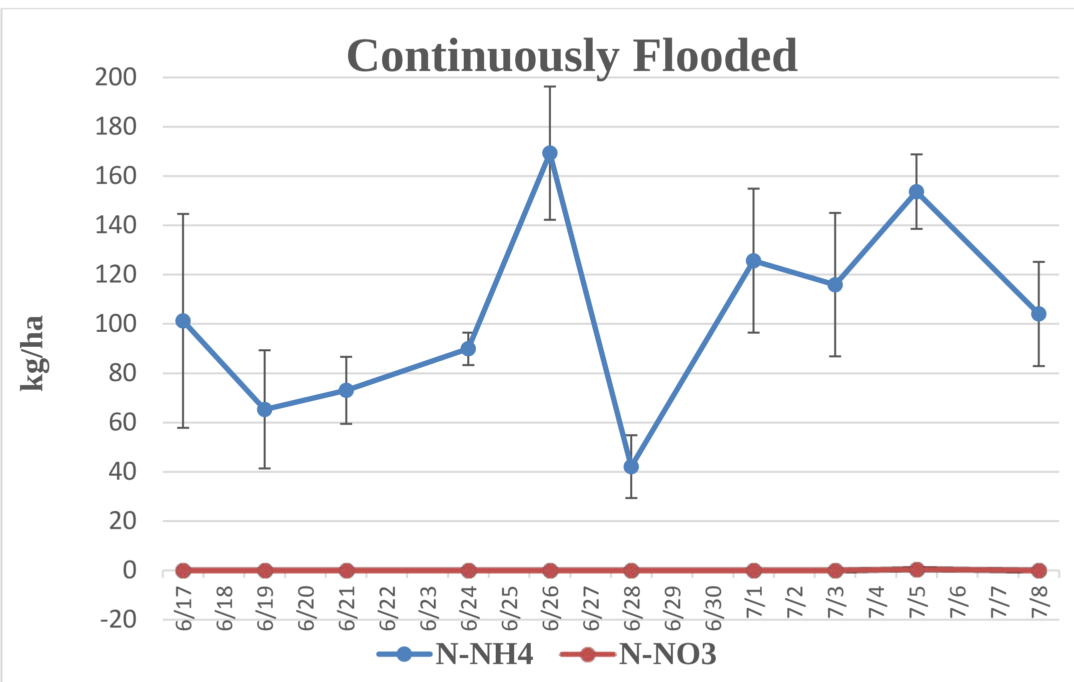


Figure 2. Soil extractable mineral N (NO_3 and NH_4) at the Rice Experiment Station (RES). Data are for treatments that were continuously flood (top) and those that were periodically drained for crop establishment (bottom). Shaded area indicates drying periods.

As expected, in both locations there is no NO_3 in the continuously flooded treatment. In this treatment the soil remains anaerobic and nitrification does not occur. In contrast, in the drained treatment, in both locations, NO_3 increases when the soil is drained (due to nitrification) and then drops to zero after flooding. This drop to zero, represents the loss of NO_3 to the atmosphere via denitrification. The total amount of NO_3 that accumulated during the two drain events was 27 and 21 kg N/ha (24 and 19 lb N/ac) at Knights Landing and the RES, respectively. This suggests that this was the amount of N lost (and thus not available to the rice) due to the drain events.

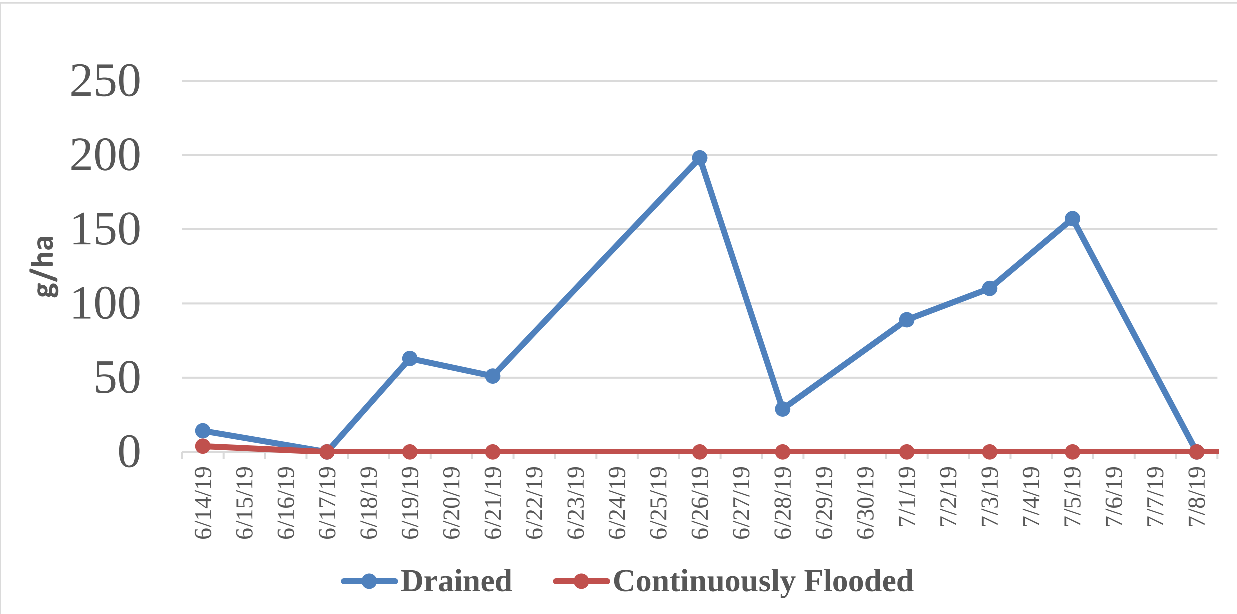


Figure 3. Nitrous oxide emissions during the drain events at the RES site.

While denitrification represents the primary N loss pathway when rice fields are drained, N can also be lost as nitrous oxide (N_2O), a greenhouse gas. Greenhouse gases were measured at the RES site and there were no N_2O emission from the continuously flooded field but 1.5 lb N/ac was lost as N_2O gas. This loss occurred primarily when the fields were drained – not when they were being reflooded.

Adding the denitrification losses and the N_2O emission losses, suggests that about 20-25 lb N/ac of fertilizer N is lost during these drainage events when there is a lot of fertilizer N in the soil (early in the season). We measured plant N uptake at panicle initiation (PI) and found that the difference in N uptake between the drained and continuously flooded treatments at both sites was much less. It averaged only 5 lb N/ac difference. We had expected to see the same difference as we saw with soil N and N_2O emission loss. This begs the question as to why our plant uptake data do not support our soil N and GHG emission data. What we think is happening is that in treatment that is drained, when the soil becomes aerobic it accelerates the decomposition of soil organic matter (we now organic matter decomposition is faster under aerobic than anaerobic conditions). This hypothesis is supported in both Figures 1 and 2 where we see that soil NH4 increases after the soil has been drained. We thus suspect that the overall losses are still in the range of 20-25 lb N/ac but these differences may not be apparent until after PI. We might expect to see differences in total plant uptake at harvest of this amount; however, we are still in the process of analyzing this data. Importantly, this suggests that in 2020 when we conduct similar experiments, it will be important to label the fertilizer N so we can directly observe what is happening with both the fertilizer and soil N.

Objective 3. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

Background

While the conventional system of growing rice under continuously flooded conditions produces good grain yields and maintains high nitrogen use efficiency, California rice growers should be prepared for situations where they might face conditions (limited water availability) or 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. Our broad objectives for this research are to (1) further develop AWD management practices that are viable for California and compare them to conventionally flooded rice and (2) identify sensitive periods in crop growth where unsaturated soil conditions can lead to yield reductions, and (3) determine the critical level the soil can dry to before negatively impacting yield. This research will demonstrate whether or not AWD 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.

Progress to date

<u>Two dry downs:</u> Research on AWD from 2012 to 2016 where we had two dry down periods of varying intensity (2 to 12 days) between 45 DAS and heading indicate:

- Regardless of dry-down severity (up to 10-12 days drying) we have seen no evidence of yield reductions relative to the continuous flood control. This is likely due to roots that go down to over a foot deep into soil layers that are not as dry.
- Nitrogen and weed management are the same for AWD as for the control. All dry downs are done after fertilizer N is taken up and canopy cover is achieved.
- Methane emissions are reduced by 40 to 90%. Nitrous oxide emissions are negligible because dry downs occur when there is low soil mineral N.
- Arsenic and methyl-mercury concentrations in the grain are reduced by over 50%. However, in Safe-AWD where dry downs were only 2-3 days As concentrations were not reduced.

<u>One dry down:</u> In 2017 we started evaluating a single dry down. This fits better into a CA rice cropping cycle. We focused on a single dry down that would coincide with a late propanil application (sometime between 40 and 50 days after seeding). Two years of research have shown the following:

- Yields, N rate and weed management are the same with a single dry down as with a continuously flooded field.
- We have looked at varying dry down periods from 2-12 days. With a roughly 5 day drain period, methane can be reduced by up to 50% (no increase in N_2O emissions). Similarly As uptake is reduced in the grain.

This research has been conducted at the RES. In 2019, we examined it on-farm. In 2017 we also examined it on-farm at three locations.

Results

In 2019, we examined it on farm at three locations (one location we could not drain the check). We asked the grower to drain a check at about 40- 45 days after seeding and leave it drained for 5 days. Actual drain times were 6 days. We monitored soil moisture during the drain times at various locations around the check and in an adjacent continuously flooded check. At harvest we took yield samples from four locations around the rained check and in the continuously flooded check. Grain samples were taken for arsenic analysis.

Grain As data are not yet available. Yield data (Table 1) show that yields were comparable between the continuously flooded check as in the AWD check. On average the AWD was slightly higher but this would not have been significant. This data support our other findings at eh RES as well as on farm (see 2107 data in Table 1), that draining a field during the mid-season for a short period of time (roughly 5 to 7 days) does not reduce yields.

Table 1. Yields and some of the yield components for AWD treatments and CF control in RES. Numbers are averages of three plots, followed by the standard error in parenthesis.

Location	**CF yield (cwt/ac)**	**AWD yield (cwt/ac)**	**Comments**
2019 Marysville	95.9	105.8	
2019 Willows	101.9	102.8	
2017 Sacramento	108.9	111.9	
2017 Willows	109.1	103.3	
2017 Arbuckle	126.7	119.8	AWD was in cold water check
Mean	**108.5**	**108.7**	

We have shown at various locations the benefits of AWD or a single mid-season drain. These include reduction in CH_4 emissions and lower uptake of arsenic and mercury into the rice grain. However, will it does not increase yields, the yields are not lowered. Furthermore, it does not lead to reductions in water use due to the heavy clay soils that rice is grown on. Adoption of such a practice is unlikely as there are no direct economic incentives (increased yields or reduced water use) to manage a field in this manner at this particular time.

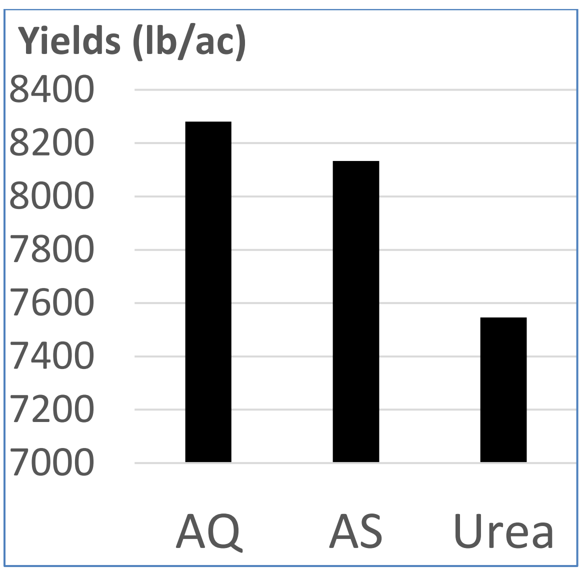
Objective 4: Other experiments

Aqua-ammonia vs Urea vs Ammonium Sulfate (AS)

In 2019, a very wet May forced some farmers to flood their fields before they had applied their aqua-ammonia. This resulted in having to supply the N needs of the crop with other forms of N- usually urea or AS. Little research has been done in this area and we received a lot of farm calls asking for advice in this area. Given the intrest, we decided to run a field trial at the RES to evaluate the different N sources.

In all cases, 150 lb N/ac was applied. For aqua, this was applied preflood as normal; however, the soil was wet at time of application. The urea and AS were applied in 4 splits: 2, 4, 6 and 7 wks after planting. The amount of N applied in each split was 20, 50, 50 and 30 lb N/ac, respectively. Treatments were replicated three times. The field was planted and flooded on June 14 using M-206. A GreenSeeker measured NDVI prior to PI. At harvest, combine yields took two areas in each plot.

Yields were overall low due to the late planting. The yields were highest in the aqua and ammonium sulfate treatments (not significantly different from one another) and significantly lower in the urea (Figure 1). NDVI values show that aqua had the lowest NDVI early on while ammonium sulfate had the highest. By mid-August, NDVI values were similar for all treatments. Future research will look at different N sources and mixes.



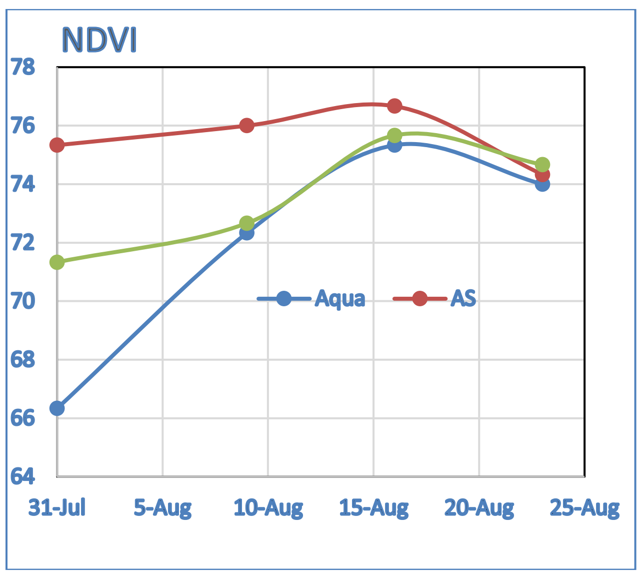


Figure 1. Yields and NDVI (GreenSeeker) for three different N sources applied to rice in 2019. Urea yields were significantly lower than the other N sources.

Regiment (does it affect rice yields?)

The herbicide Regiment CA (Valent, USA) is a common herbicide in CA. It is known to stunt rice and growers often apply a top-dress application of N after a Regiment application to help minimize this effect. In 2019, we conducted a study to determine if Regiment applications reduce rice yields and if so, does a top-dress N application alleviate this affect.

The study was done in large bins (4ft X4ft X 0.75 ft deep). A soil was chosen that contained relatively few rice weeds as the only herbicide we wanted to apply was Regiment. The following treatments were replicated 4 times:

1. 150 preplant N (NO Regiment)
2. 150 preplant N (YES Regiment)
3. 150 preplant N + 30 N topdress (NO Regiment)
4. 150 preplant N + 30 N topdress (YES Regiment)

The 150 N preplant fertilizer was urea placed 3 inches below the soil surface (to mimic aqua). P and K were added at planting. The Regiment was applied on July 3 at a rate of 0.8 oz/ac of formulated product is the highest rate on the label. This was mixed the surfactant Dyne-Amic (Helena Agri-Enterprises) at 10 floz/ac. The N top-dress was applied immediately after. Rice (M-206) was planted in the bins on June 7. We attempted to maintain a 2" flood although this was difficult due to leak in some of the bins. However, this did not appear to affect yields.

Our Results are somewhat inconclusive. First, one week after the Regiment application, there e was a noticeable difference in height between the treatments. The rice with the Regiment application was noticeably stunted. Both of the treatments receiving the top-dress N applications had lower yields than the treatments that did not. This may have been due to blanking due to excess N but this was not tested. Combining all treatments and simply examining the treatments with or without Regiment, indicates that yields were similar regardless of Regiment treatment (Figure 2). Given that this experiment was done in bins and was planted quite late, recommendations should not be made from this data.

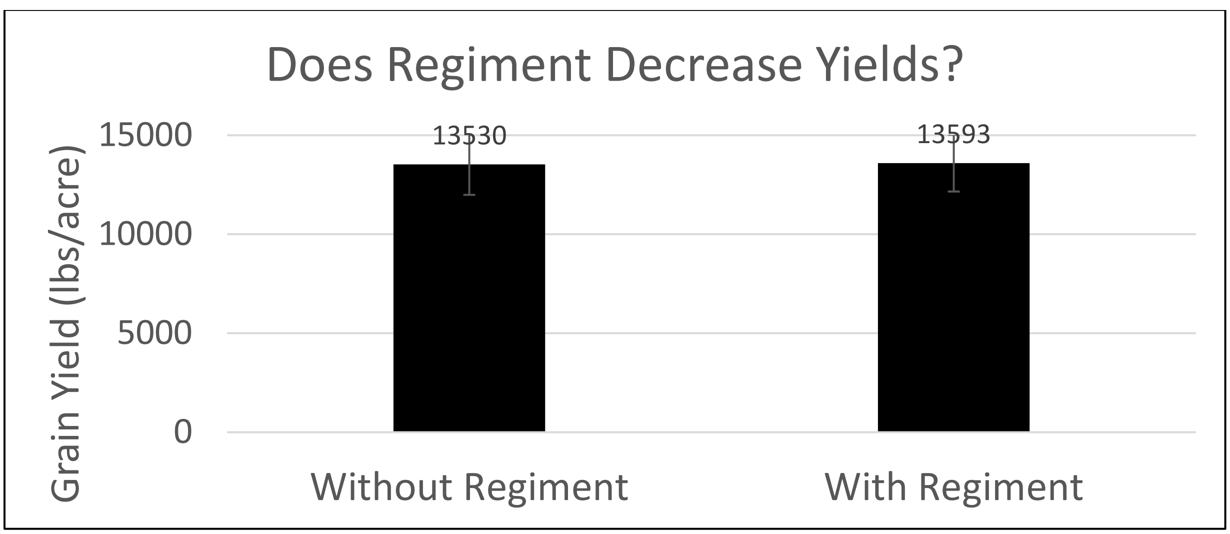


Figure 2. Rice yields comparing treatments that received or did not receive Regiment herbicide. Yields are averaged over treatments that received or did not receive top-dress N fertilizer.

Rice yields in No-till vs tilled fields

It is not uncommon, when rice fields are fallowed for a season that farmers level the field during the summer it is being fallowed. This operation is similar to the leveling that may take place in the spring before planting. We wanted to know if it would be possible to plant rice onto the leveled field in the following spring without any additional tillage. This is somewhat similar to planting rice on a stale seedbed. This research may also have implications for controlling weedy rice.

In 2018, a 0.5 acre plot was leveled. In May 2019, we sprayed weeds that had come up during the spring rains. Within the plot, we tilled (and rolled) two areas with a disc to simulate typical spring tillage. Just before planting we applied 205 lb N/ac applied as urea before flood to dry ground. Planting (M-206) was done on June 14. At harvest, we used a small combine to obtain yields from each plot.

At planting, the no-till plots had a lot of spring weeds. Weeds may not be a problem if they are controlled with a broad spectrum herbicide before planting. The dead weeds may help anchor the seedlings early in the season and prevent winds from blowing the young seedlings to levee edges. Yields were low in both treatments – possibly due to the late planting date. Yields were also similar between the two treatments (Figure 3).

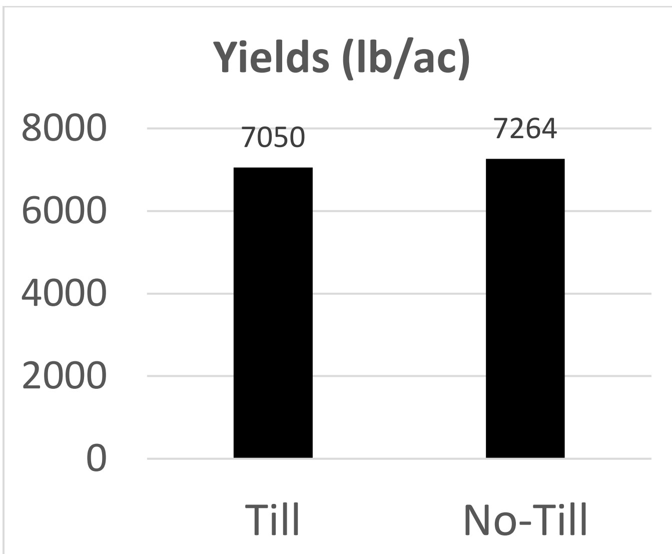


Figure 3. Yields from the Tilled and No-till plots in 2019.

PUBLICATIONS OR REPORTS:

PUBLICATIONS (Rice publications 2017-19):

1. Montazar, A., Rejmanek, H., Tindula, G.N., Little, C., Shapland, T.M., Anderson, F.E., Inglese, G., Mutters, R.G., Linquist, B., Greer, C.A., Hill, J.E., Snyder, R.L. (2017) A crop coefficient curve for paddy rice from residual of the energy balance calculations. *Journal of Irrigation and Drainage Engineering*. 143(2) doi: 10.1061/(ASCE)IR.1943-4774.0001117.
2. Sharifi, H., R.J. Hijmans, J.E. Hill, B. Linquist (2017) Using stage-dependent temperature parameters to improve phenological model prediction accuracy in rice (Oryza sativa) models. *Crop Science* 57:444-453.

3. Tanner K.C., L. Windham-Myers, J.A. Fleck, K.W. Tate, S. McCord, B.A. Linquist (2017) The contribution of rice agriculture to methylmercury in surface waters: a review of data from the Sacramento Valley, California. *Journal of Environmental Quality* 46:133-142.
4. Carrijo, D., M. Lundy, and B.A. Linquist (2017) Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Research* 203:173-180
5. Brim-Deforest, W.B., K. Al-Khatib, B.A. Linquist, and A.J. Fisher (2017) Weed community dynamics and system productivity in alternative irrigation systems in California rice. *Weed Science* 65:177-188. doi: 10.1614/WS-D-16-00064.1
6. Espe, M.B., J.E. Hill, K. McKenzie, R.J. Hijmans, L.A. Espino, R. Mutters, M. Lienfelder-Miles, C. van Kessel, B.A. Linquist (2017) Point stresses during reproductive stage rather than warming seasonal temperature determines yield in temperate rice. *Global Change Biology* 23:4386-4395 DOI: 10.1111/gcb.13719.
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PRESENTATIONS (2019)

Linquist, Bruce. Nutrient management in California rice systems. Rice winter grower meetings. January 17, 18 and 22, 2019. Woodland, Richvale, Willows, Colusa and Yuba City.

Linquist, B.A. and T. Rehman. 2019. Accessing mid-season plant N demand. Presentation at the Rice Field Day. August 28, 2019. Biggs, CA.

Geoghan, P. and B.A. Linquist. 2019. Measuring and Modeling nitrogen losses from aqua ammonia fertilizer during dry down periods in conventional California rice production systems. Presentation at the Rice Field Day. August 28, 2019. Biggs, CA.

Perry, H., D. Carrijo, and B.A. Linquist. 2019. The effects of midseason drainage on greenhouse gas emissions and yield in California rice systems. Presentation at the Rice Field Day. August 28, 2019. Biggs, CA.

Chuong, T. and B.A. Linquist. 2019. The effects of fertilizer sources and placement on ammonia volatilization losses from water-seeded rice systems in the Sacramento valley. Presentation at the Rice Field Day. August 28, 2019. Biggs, CA.

Rehman, T. and B.A. Linquist. 2019. Using drone technology to guide midseason nitrogen fertilizer applications. Presentation at the Rice Field Day. August 28, 2019. Biggs, CA.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Objective 1. Mid-season N status and accessing the need to top-dress

Analysis of Green Seeker data from 2015 to 2019 indicates:

1. The Green Seeker NDVI is a good indicator of above ground N content (or total plant N uptake) at panicle initiation (PI) but a relatively poor indicator of biomass and of N concentration in the plant at PI.
2. A Response Index (max observed NDVI in enriched plot/treatment NDVI) is a more robust method of determining the need for top-dress N. A Response Index of 1.1 or greater indicates a good chance of a positive yield response to top-dress N fertilizer.
3. Using a drone mounted camera (passive sensor), the Green Seeker NDVI was superior to the drone NDVI for detecting crop N status. However, the drone NDRE (Normalized Difference Red Edge) was superior to GreenSeeker NDVI in quantifying crop N status. The Response Index for the NDRE taken from a drone, also show a critical vale of 1.1. If it is greater than 1.1, it is highly likely that there will be a positive yield response to top-dress N.

Objective 2. Potential N losses early in the season due to flooding/draining events

Fertilizer nitrogen losses due to draining and reflooding dry seeded rice fields result in roughly 20-25 lb N/ac. These losses are primarily due to denitrification but losses due to N_2O GHG emissions are also result in 1-2 lb N/ac loss. These losses may be partially offset by increased mineralization of soil organic matter when the soil is dried down. Further research will quantify these separately and help develop N recommendations for these systems.

Objective 3. Develop management practices for growing rice under conditions of alternate flooded/dry soil conditions.

Alternate wetting and drying (AWD) has been evaluated in California since 2012. We have examined both two and single dry down events during the season, as well as differences in severity of the dry down (drying from 2 days to up to 12 days). Dry downs have typically started around 40 days after sowing. What we have found are:

1. In all the years of study, only in 2017 did AWD reduce yields and this was at the most severe drying treatment (11 days). The cause of low yields in that one treatment was likely due to 2017 being an abnormally warm year.
2. Nitrogen and weed management are the same for AWD as for the control. All dry downs are done after fertilizer N is taken up and canopy cover is achieved.

3. Methane (CH_4) emissions reduced with AWD by 40 to 90%. Lower reductions are when the field is only dried for a 2-3 day period while greater reductions we reported with 8 or more days of drying.
4. N_2O emissions were usually negligible. However, when draining early (i.e. 35-37 days after sowing) N_2O emissions did occur because, at this early juncture there was still mineral fertilizer N in the soil. Draining a few days later, usually meant all mineral N had been taken up by the plant and there was no N_2O emissions.
5. Grain As concentrations were reduced by 50% when dried for at least 8 days. Drying for only 2 to 5 days did not reduce grain As concentrations. We saw similar reductions in grain MeHg concentrations.
6. On-farm studies conducted in 2017 and 2019, where a full check was drained at 40-45 days for a 2 to 6 day period, confirm findings from the RES.

Objective 4: Other experiments

1. Split applications of only ammonium sulfate were similar to aqua ammonia but were superior to split applications of only urea. It is likely however that the best approach may be to apply ammonium sulfate in the first application and then urea in the later applications. This will be tested in 2020.
2. Regiment appeared to stunt rice growth following application but it did not reduce yields in our experiment.
3. Yields in no-till plots were the same as yields in plots that were tilled. However in both cases yields were low (less than 73 cwt/ac).