PROJECT NO. RM-4

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:

For our 2009 research we had the following objectives:

Objective 1. To improve N fertilizer guidelines for California rice growers using alternative water management strategies and provide an analysis of the economic tradeoffs associated with early season drains in relation to fertility management.

Objective 2: To test improved N management strategies for conventionally managed (with respect to water) fields on a large scale.

Objective 3: Evaluate the effectiveness of early (fall or early spring) applied P and P applied 30 days after seeding (DAS) in relation to P availability and rice growth.

Objective 4: Effect of P timing on algae, water P concentration, and yields (in collaboration with David Spencer)

The algae portion of this research was conducted by David Spencer and will be included in his report.

SUMMARY OF 2009 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1. To improve N fertilizer guidelines for California rice growers using alternative water management strategies and provide an analysis of the economic tradeoffs associated with early season drains in relation to fertility management.

No growers were identified to work with us on this area of research, because they did not plan on having extended drain periods (a prerequisite for our research). We have researched this area a lot in the past and have reported these results to growers. Our research has shown that extended drain periods are not a good option due to the potential for high N losses. Thus, the inability to find participating growers suggest that we have gotten the message out.

Results from past research in this area have been written up into a manuscript and has been submitted to California Agriculture (see below).

Objective 2: To test improved N management strategies for conventionally managed (with respect to water) fields on a large scale.

On-farm experimental small plot research conducted from 2005 to 2008 showed that if growers eliminate their preplant starter N (N applied to the soil surface at planting) and instead increase their aqua-N rate by that same amount, rice yields and N use efficiency are increased. Results from this work have been published (see Linquist et al., 2009 in the Publications section at the end of this report). In 2007, we began working with farmers to test this on a large scale. This involved growers testing two treatments:

(1) growers standard practice of aqua and starter N as preplant N and
(2) all the preplant N as aqua-N (same total N rate as treatment 1).

Growers will use their equipment to apply the material. Treatment 2 was either applied to a full check or to two adjacent field length passes in their fields. At harvest, the plots will all be harvested using a combine equipped with a yield monitor.

In 2009 this was continued on 5 sites (same sites as the delayed P study); however at only one of these sites were the treatments comparable to other grower trials in 2007 and 2008. That is that the grower applied a higher aqua-N rate in treatment 2. Most growers applied equivalent aqua-N rates to the two treatments but simply delayed the starter fertilizer application. So here, we present the one grower that did have comparable treatments. The other growers and the results from those fields will be discussed in Objective 4 (late P applications on algae growth).

Table 1. Rice yields as affected by N management in field scale studies from 2007-2009. Total N rates for both treatments were similar.

Year	Field	Rice grain yield (lb/ac)		
		All N applied as aqua	Aqua + starter (conventional)	Yield difference
2007	1	10,001	9,531	+470
2008	2	10,040	9,710	+330
2008	3	9,419	8,529	+890
2008	4	10,570	10,275	+295
2009	5	10,200	10,350	-150
MEAN		**10,046**	**9,679**	**+367**

Table 1 shows all of the data from on-farm field scale trails between 2007 and 2009. Of the five trails, at four of the locations yields were higher when all of the N was applied as aqua-N. In 2009, yields were 150 lb/ac less when all of the N was applied as aqua. Analyzing all of the data using regression analysis shows that the yield response to applying all of the N as aqua was greatest when yields in the conventional treatment was lowest. Linquist et al. (2009) reported that applying all of the N as aqua increased N use efficiency. What Figure 1 suggests is that the lower yielding sites were more N deficient so the response to available N was greater. At the higher yield levels both treatments received near adequate levels of N so the response to the available N was less.

These large scale on-farm trails confirm results of on-farm small plot researcher managed trails and confirm that growers should apply as much of their N as possible as aqua-N. Placing the N 3-4 inches below the soil surface protects the N from denitrification losses and makes more of it useable to the crop. We have a few recommendations:

1. If growers need to apply their P and K before planting they should use a fertilizer blend with the lowest amount of N as possible (i.e. 11-52-0 or 5-26-30). For example, if a grower normally applied 150 lb N/ac (110 lb/ac as aqua-N and 40 as a starter), we would recommend applying 140 lb N/ac as aqua-N and 10 lb N/ac as 5-26-30. NOTE we are not recommending this blend per say but using it as an example.
2. A grower could decide to apply the starter blend (low in N) later in crop growth (i.e. between 20 and 30 days after sowing) by airplane. This would eliminate the need to apply at planting and may allow for a more timely planting date. This Dr. Spencer has shown this to reduce algae (see Objective 4 and David Spencer's report).

3. The grower could decide to apply P and K in the Fall before turning in straw stubble. This practice is best if (1) the field is not P deficient (roughly 90% of fields are not deficient) but growers are applying maintenance levels of P and K and (2) the P and K source does not contain N. Any N applied at this time will not be available in any significant amount by the following spring when rice is planted.

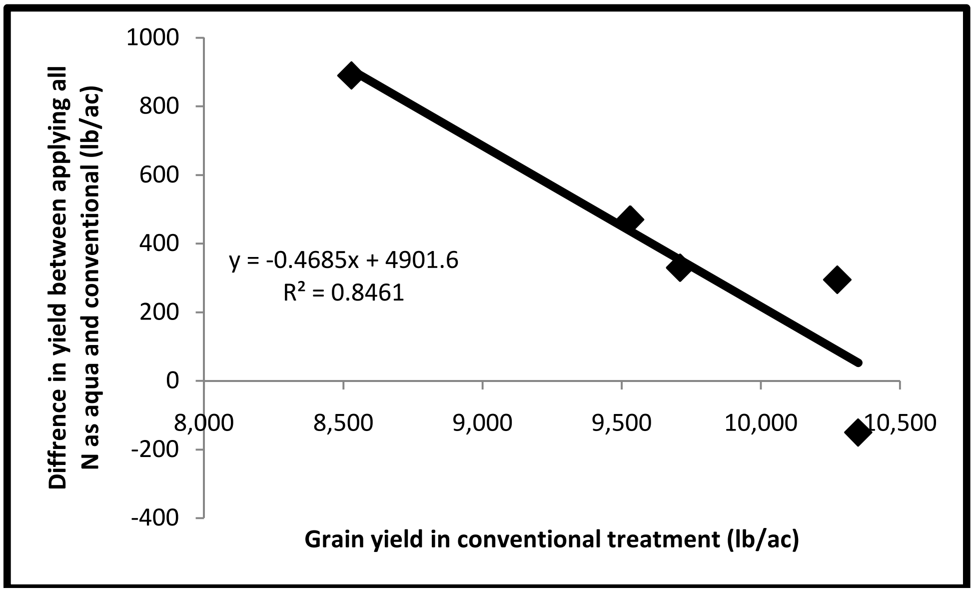

Figure 1. Grain yield response to applying the entire N rate as aqua-N and applying it as conventionally done (aqua-N and starter) with respect to grain yields in the conventional treatment.

Objective 3: Evaluate the effectiveness of early (fall or early spring) applied P and P applied 30 days after seeding (DAS) in relation to P availability and rice growth.

Background

Research conducted in 2007 and 2008 has shown that surface applications of phosphorus (P) fertilizer increase the growth of weeds and algae, suggesting that changing the timing of P fertilizer application may reduce weed and algae growth. However, the effect of alternative P timing on the growth of flooded rice in California has not been studied. Therefore, the objective of this study was to determine the effect of variations in the timing of P fertilizer application on rice growth, P uptake and yield.

In 2008 we examined the effects of alternative P fertilizer timing and found that P fertilizer application before spring tillage and at mid-tillering (35 DAP) had no negative effect on plant P or grain yield compared to conventional preplant, surface application of P fertilizer. However, none of the fields in the 2008 study demonstrated a significant yield response to P fertilization. Therefore, in order to differentiate the response of rice to variations in P timing, in 2009 we conducted a similar study on two fields deficient in available P as predicted by Olsen P values below 6 mg P/kg soil. Both fields were located in Butte County and had similar soils, but varied in management. In Field A, straw from the previous crop was fall-incorporated into the soil and flooded over the winter. In Field B, straw residue was burned and no permanent flood was held over the winter. We hypothesized that treatments with TSP applied to the soil surface in the fall prior to cropping (FP), immediately prior to planting (SP), at mid-tillering (35 DAP), and prior to panicle initiation (49 DAP) would vary in biomass accumulation and P uptake. However, based on the minimal treatment differences observed in 2008, we also hypothesized that there would be no effect on grain yield between these treatments. We included a control treatment with zero P fertilizer (ZP) to verify that rice would respond to P fertilization in these locations.

Methods

In each field we imposed the 5 treatments described above in 6 randomized complete blocks. P fertilizer was applied in the form of TSP at a rate of 56 kg P2O5 / ha (50 lb P2O5 / ac) in plots at least 5m x 2.5m. Above ground biomass samples were taken from the plots at 21 DAP, 35 DAP, and 60 DAP. At 35DAP (mid-tillering) Y-leaf plant samples were also taken. Plant samples were dried at 60° C, weighed and analyzed for total P and extractable phosphate. At physiological maturity rice was harvested from a 1mx1m area in each plot. Plants were dried at 60° C and weighed; grains were separated and weighed. Soil samples were taken from the Fall P as well as from the Spring P and Zero P plots at the following times: in November 2008, prior to the application of any TSP; in mid-March 2009, after the fields had been drained in preparation for field operations; and at the end of April 2009, after all the field operations had been completed, immediately before planting. Since the 35 DAP and 45 DAP treatments were effectively Zero P plots until 35 and 49 days after planting, respectively, we took no soil samples from these plots and only sampled plants from these plots at 60 DAP and later.

Soil Olsen P (mg P/kg soil)				
		November 2008 (pre-Fall P application)	Spring 2009 (pre-tillage)	Spring 2009 (post-tillage, pre-Spring P application)
FIELD A (incorporated straw)	Spring P	3.7 A	3.9 B	4.2 A
	Fall P	3.6 A	5.8 A	4.4 A
	Zero P	3.7 A	3.8 B	4.7 A
FIELD B (burned straw)	Spring P	4.5 A	3.0 B	3.2 B
	Fall P	4.7 A	8.0 A	6.5 A
	Zero P	4.2 A	3.0 B	3.5 B

Table 1. Differences in Olsen P values at three sampling times between plots where TSP was surface-applied in November 2008 (Fall P) and where it was not (Spring P and Zero P). Mean separation at p<0.05 using Tukey HSD.

To create the Fall P treatment we applied 12.59 kg TSP over 1005 m^2 (50 pounds P_2O_5 per acre) in November 2008. We marked the center of this area using GPS and in the spring we established our plots at this location. A buffer of 60 meters between the Fall P plots and the other plots was created in order to ensure that the fall applied TSP did not move into the other plots during spring tillage and land planing. Table 1 shows changes in Olsen P values in the Fall P plots over the three soil sampling times. In Field A, where the straw had been incorporated, soil from plots with fall-applied TSP showed a 50% increase in available P over the winter. In Field B, where the residue was burned, available P increased 167% in the fall applied plots. Between the second and third soil sampling time, the available P in the Fall P plots was reduced in both fields, and in Field A the difference between the Fall P plot and the Zero P and Spring P plots disappeared. However, the plant P data at 35 DAP belies this finding (Figure 1). Therefore, the discrepancy may be explained by sampling errors and/or differences in tillage depth between the two fields.

Results

P uptake

At mid-tillering (35 DAP) rice in the Spring P treatment had taken up more total P (89% in Field A and 37% in Field B) and extractable phosphate (126% in Field A and 49% in Field B) than the

Fall P. Likewise, rice in the Fall P treatment took up 95% more total P and 110% more extractable phosphate than the Zero P (ZP) treatment in Field A and 227% more total P and 280% more extractable phosphate than the Zero P (ZP) treatment in Field B. The Y-leaf concentrations for total P and extractable phosphate followed the same pattern. Spring P treatments had 0.29% total P and 1020ppm extractable phosphate in Field A and 0.34% total P and 1250ppm extractable phosphate in Field B. Fall P treatments had 0.22% total P and 630ppm extractable phosphate in Field A and 0.27% total P and 890ppm extractable phosphate in Field B. Zero P treatments had 0.16% total P and 410ppm extractable phosphate in Field A and 0.12% total P and 340ppm extractable phosphate in Field B. (Please refer to Figure 1 for visual summary of P uptake at 35 DAP.)

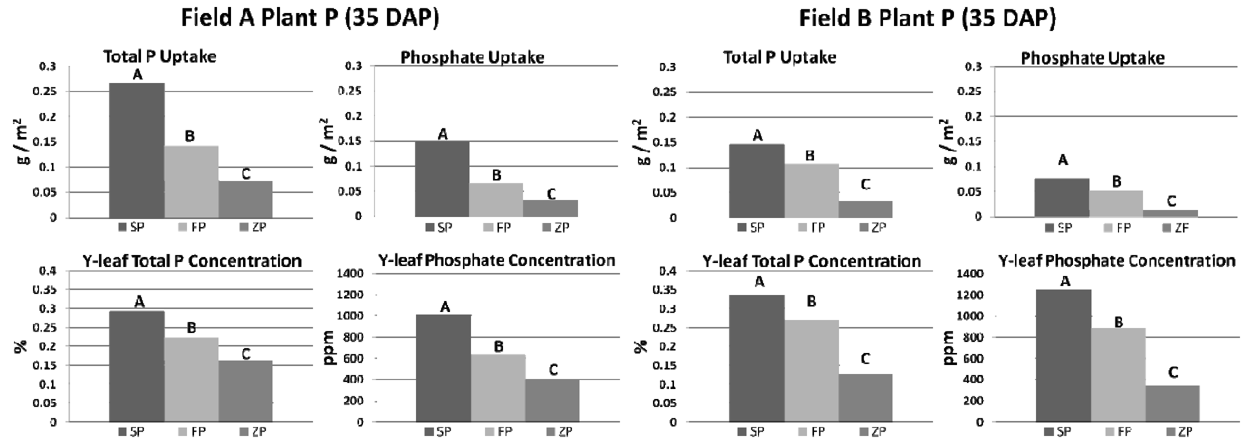

Figure 1. P uptake and Y-leaf concentration at mid-tillering in Field A and Field B. Mean separation at p<0.05 using Tukey HSD.

Both Fall P and Zero P treatments were below established critical levels of tissue P concentration for rice at mid-tillering. However, because the Fall P took up substantially more total P and extractable phosphate than the Zero P treatment, fall applications of P fertilizers may still be a viable management option, but a higher rate would probably be necessary on fields with P-deficiencies comparable to those in this study. Although not compared statistically, a visual comparison indicates that there was more fertilizer P available in Field B (burned straw) than in Field A (incorporated straw).

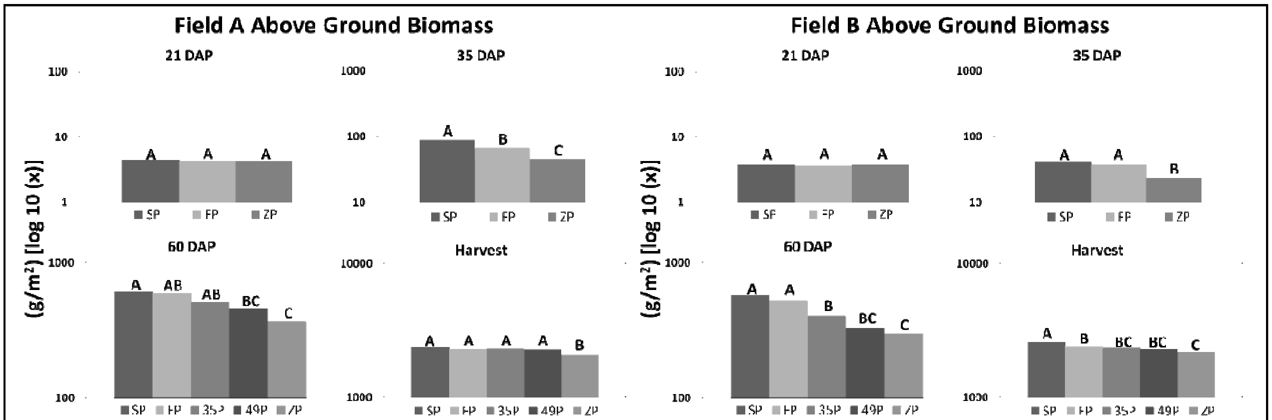

Figure 2. Above ground biomass in Field A and Field B at 21 days after planting (DAP), 35 DAP, 60 DAP and harvest. Mean separation at p<0.05 using Tukey HSD.

Above Ground Biomass

Although there were no differences in biomass accumulation between the Fall P, Spring P and Zero P treatments at 21 DAP, by 35 DAP, the Fall P and Spring P treatments had, respectively, 49% and 95% greater biomass than the Zero P treament in Field A and 62% and 78% greater biomass than the Zero P treatment in Field B. The treatments with P fertilization continued to accumulate greater biomass than the Zero P treatment through 60 DAP and harvest, with the 35 DAP and 49 DAP treatments accumulating less biomass than the Spring P and Fall P treatments (although these differences were not statistically significance in every instance). While the Fall P treatment tended to accumulated more total biomass than the 35 DAP treatment, the Fall P treatment had a lower harvest index and lower yields than the 35 DAP treatment, indicating that more of the P fertilizer was directed to grain filling in the 35 DAP treatment than the Fall P treatment. That the Fall P treatment as well as the 35 DAP and 49 DAP treatments accumulated greater biomass than the Zero P treatment indicates that the TSP applied to the plots either in the fall or between mid-tillering and panicle initiation is plant-available. (Please refer to Figure 2 for a visual summary of above ground biomass accumulation.)

Yield

The grain yields in the Fall P and the 35 DAP treatments were not significantly different than the Spring P treatment in either field. In Field A only the 35 DAP and Spring P treatments were significantly greater than the Zero P treatment. In Field B the Fall P, 35 DAP and Spring P treatments were all greater than the Zero P treatment, while the 49 DAP treatment was not. Relative to the Zero P treatment, the 35 DAP treatment increased yields 13% in Field A and 11% in Field B. The Fall P treatment increased yields 11% over the Zero P treatment in Field B but only 5% in Field A.

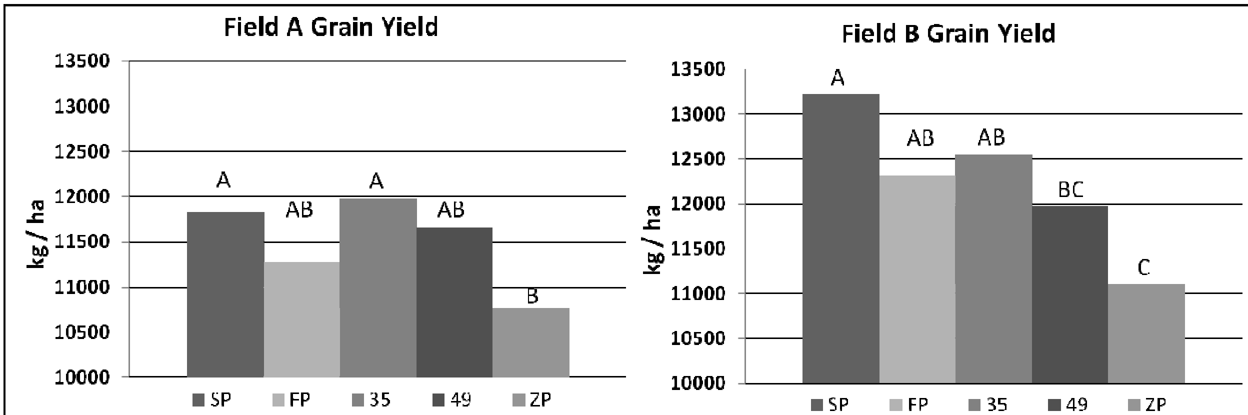

Figure 3. Grain yield in Field A and Field B for all four P fertilizer application timings as well as for the Zero P treatment. Mean separation at p<0.05 using Tukey HSD.

These results suggest that fertilizer P applied during mid-tillering may be a viable alternative to pre-plant applications without significant yield penalty. Fall applications may also be a viable alternative, especially considering that fewer than 5 percent of rice fields in California are P-deficient. In cases where a field is P-deficient, a fall application of P fertilizer may require a higher rate. Although the yields for the 49 DAP treatment trended higher than the Zero P treatment, yields as well as biomass accumulation at 60 DAP and harvest were lower in the 49

DAP treatment (with one exception) than all the other treatments with P fertility. Given this, 49 days after planting might best be viewed as a cutoff for mid-season appplications of P. (Please refer to Figure 3 for a visual summary of yield differences between the treatments.)

Objective 4: Effect of P timing on algae, water P concentration, and yields (in collaboration with David Spencer)

Early season algae growth is a problem for many rice growers in California-especially early in the growing season as the crop gets established. Identifying cost effective measures to control algae that ensure minimal environmental impact is an important goal of the rice industry. High P water concentrations have been shown to favor algae growth. The objective of this research was to determine if delaying fertilizer applications reduces algae growth. This aspect of the research was conducted by David Spencer and is included in his report. It was our objective to determine if late P applications reduced grain yields and if there may be a detrimental effect on water quality. P is a constituent of concern in California's surface water. As an industry we need to make sure that we minimize the P concentration of water leaving rice fields.

To accomplish our objectives we identified five growers to collaborate with us. Each grower had a side-by-side field (or check) comparison of two practices:

1. Conventional P fertilizer practice of applying P before planting
2. Delaying the P fertilizer application until later in crop growth (in our case between 16 and 32 days after planting)

In each of these fields we monitored the P concentration of water coming into the field, in-field water and water leaving the field (in a number of fields, water never left the field). At harvest growers determined yields in each field or check using their combines.

Results showed that delaying P application reduced algae growth (see Spencer report). In most field comparisons the total amount of P and K were similar between the treatments; however in field C and R the N rate was 20 and 6 lb N/ac higher in the conventional treatment, respectively. In the J field the delayed received 7 lb N/ac more than the conventional. Some of these differences reflect availability of different blends. In terms of yield, delaying the P application had little to no effect on 3 of the 4 fields where data is available (differences averaged 120 lb/ac which is insignificant for these sorts of trials). However in the K field, yields were 1266 lb/ac lower when P was delayed. We are not sure why this is the case. It does not correspond with any of the other data we have presented in this report regarding either delayed N or P applications. In Objective 3 above (and at the other locations in this study), our data indicate that applying P later in crop growth, but before 35 days after planting, has no significant effect on grain yields. Also, at this K field, there was very little difference in N management as the topdress N only received 7.5 lb N/ac. We suggest that these yield differences may be due to differences in soil properties between the two fields.

Table 1. Fertility management practices and grain yields for the five study locations.

Site	P practice	Aqua N rate	Preplant surface N rate	Topdress N	Total N	Prepalnt P	Topdress P	Total P	P delay	Grain yields
			lb N/ac				lb P2O5/ac		days	lb/ac
N	Conv	145	7.5	0	153	39	0	39	0	9770
N	Delayed	145	0	7.5	153	0	39	39	32	9610
K	Conv	145	7.5	0	153	39	0	39	0	9920
K	Delayed	145	0	7.5	153	0	39	39	26	8654
C	Conv	120	27.5	0	148	44	0	44	0	NA
C	Delayed	120	0	7.5	128	0	39	39	16	NA
J	Conv	120	24	0	144	39	0	39	0	8800
J	Delayed	116	0	35	151	0	44	44	28	8750
R	Conv	105	40	14	159	40	18	58	0	10,350
R	Delayed	140	0	13	153	0	61	61	28	10,200

NA=not yet available

The effect of P fertilizer management on water P concentrations is shown in Figure 1. In the conventional fields water P concentrations were higher than the delayed P fields at the onset of the initial flood – as would be expected. The magnitude of P concentration varied significantly between fields. In the conventional treatment water P concentrations gradually lowered and reached a minimum after about 10 days after which water P concentrations tended to rise again in 2 of the 5 fields. The reason for this is not clear. In the delayed P fields water P concentrations were low until the P application (16-32 days after planting), when P concentrations spiked to very high levels in some fields. After the spike water P concentrations lowered to a minimum after about 10 to 14 days. The magnitude often spike and the period it took for water P concentrations to lower varied widely among fields.

Based on our results, we can summarize that:

1. Delaying the P application by 16 to 32 days does not impact yields (but does reduce algae-see Spencer report)
2. Delaying the P application may cause a water quality concern if water is flowing out of the field from the time of application until about 2 weeks after application
3. We suggest applying the delayed P in conjunction with other water holding practices to avoid this potential problem

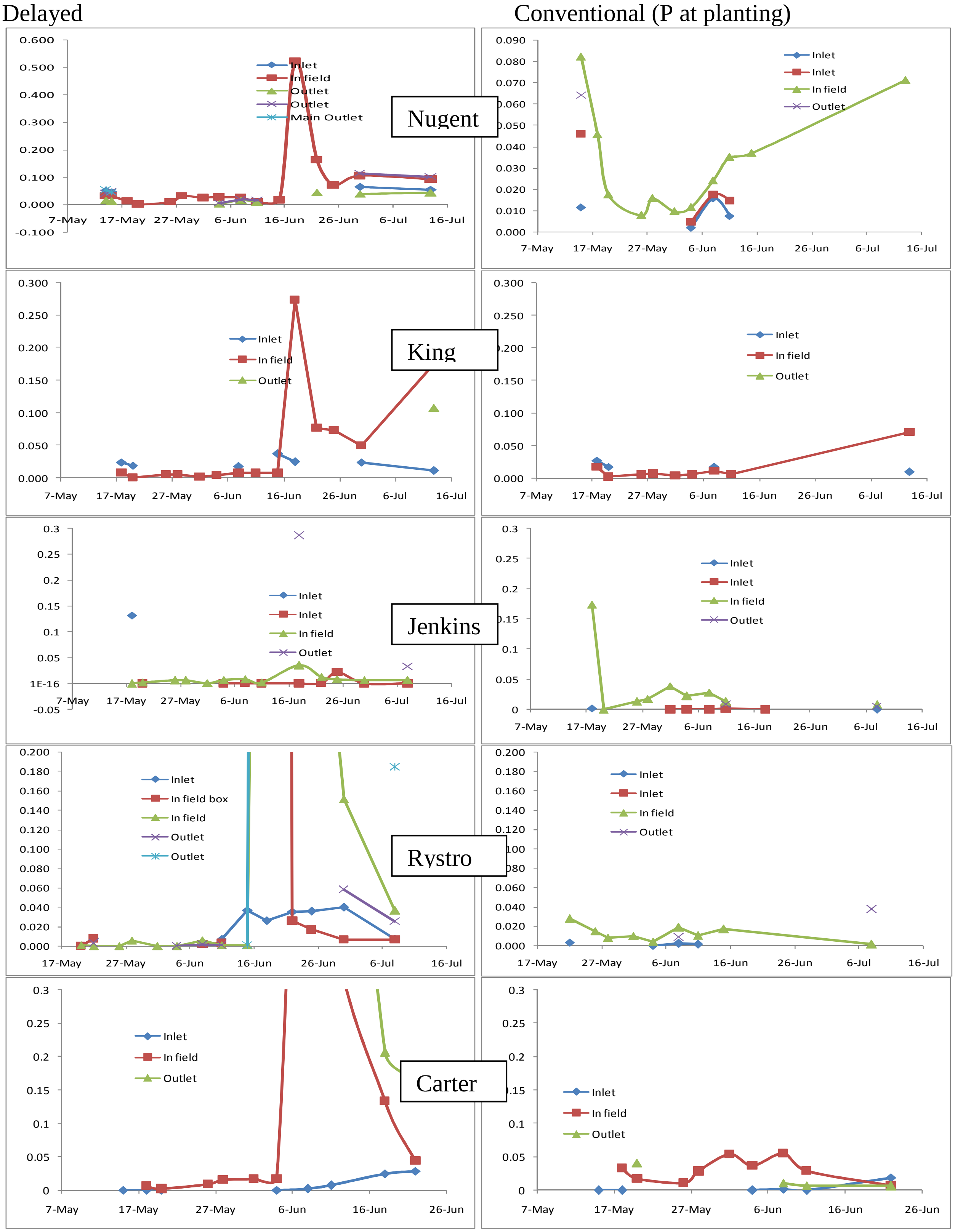

Figure 1. Water P concentrations in rice field inlets, in-field waters and outlets as affected by the time of P application.

PUBLICATIONS OR REPORTS:

Publications:

1. B.A. Linquist, J.E. Hill, R.G. Mutters, C.A. Greer, C. Hartley, M.D. Ruark and C. van Kessel. (2009). Assessing the necessity of surface applied pre-plant nitrogen fertilizer in rice systems. Agronomy Journal 101:906-915.

2. Ruark, M.D., B.A. Linquist, J. Six, C. van Kessel, C.A. Greer, R.G. Mutters, and J.E. Hill. (In Press 2009). Seasonal losses of dissolved organic carbon and total dissolved solids from rice production systems in northern California. Journal of Environmental Quality (In Press)

3. Linquist, B.A., K. Koffler, J.E. Hill and C.van Kessel. (submitted). The impact of rice field drainage on nitrogen management. California Agriculture.

Presentations:

4. B. Linquist, J. Hill, M. Lundy, C. Pittelkow, D. Spencer, and C. van Kessel. 2009. Fertilizer guidelines for alternative and conventionally managed rice systems. Rice winter grower meetings. Jan 20 and 22, 2009
5. B. Linquist, M.D. Ruark, C. van Kessel, J. Six, R.G. Mutters, C.A. Greer, and J.E. Hill. 2009. An overview of rice production impacts on water quality. Rice winter grower meetings. Jan 20 and 22, 2009
6. Pittelcow, C., B. Linquist, C. van Kessel, J. Hill, A. Fisher, L. Godfrey, L. Espino, C. Greer, and R. Mutters. 2009. Nitrogen fertility management in alternative rice establishment systems. Poster presentation at the Rice Field Day. Biggs, CA August 29, 2009.
7. B. Linquist, J. Hill, M. Lundy, K. Koffler, and C. van Kessel. 2009. Surface applied starter fertilizer in California rice system: When do you need it and how do you manage it? Poster presentation at the Rice Field Day. Biggs, CA August 29, 2009.
8. M. Simmonds, B. Linquist, J. Pena, R. Plant, and C. van Kessel. 2009. Spatial variability of soil nutrient availability and yield in rice soils: The role of flood water movement. Poster presentation at the Rice Field Day. Biggs, CA August 29, 2009.
9. P. Wild, B. Linquist, C. van Kessel, and J. Lundberg. 2009. Evaluation of nitrogen sources for organic rice production. Poster presentation at the Rice Field Day. Biggs, CA August 29, 2009.
10. Linquist, B.A., M.D. Ruark, C. van Kessel, J.E. Hill and J. Six. 2009. Carbon and Nutrient Losses in Rice Field Drainage Water. Presentation at the ASA-CSA-SSSA annual meetings. Pittsburgh, PA Oct 2-5, 2009.
11. Lundy, M.E., van Kessel, C., Hill, J.E., and Linquist, B.A. 2010. "The Effect of Variations in P Fertilizer Timing on the Growth of Flooded Rice in California." (Poster) *Rice Technical Working Group Meeting 2010*, Mississippi State University. Biloxi, MS, February 22-25,2010.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

1. Field scale trials confirm results of on-farm small plot researcher managed trails indicating that growers should apply as much of their N as possible as aqua-N. Placing the N 3-4 inches below the soil surface protects the N from denitrification losses and makes more of it useable to the crop. Recommendations have been developed for this practice.

2. Delaying P applications until 35 days after planting provides yields that are the same as when P is applied just before planting. Applications of P in the fall (just before straw incorporation) increases yields relative to when no P is applied but growers in P deficient soils may need to apply more P in the Fall. Our data suggest that for the majority of growers who do not have P deficient soils that P applications can be made in the Fall, at planting or after planting without negative effects to grain yields.
3. Delaying the P application (starter application in this study) by 16 to 32 days does not impact yields (but does reduce algae-see Spencer report). However, delaying the P application may cause a water quality concern if water is flowing out of the field from the time of application until about 2 weeks after application. Thus, we suggest applying the delayed P in conjunction with other water holding practices to avoid this potential problem.