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COMPREHENSIVE RESEARCH ON RICE
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PROJECT TITLE: Improving fertilizer guidelines for California's changing rice climate.

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Project Goal:

Our overall all goal is to develop fertilizer guidelines for California rice growers which are economic viable and environmentally sound.

In 2008 three objectives were addressed.

Project Objectives:

1. To improve N fertilizer guidelines for California rice growers using alternative water management strategies (early season drains).
2. To test improved N management strategies for conventionally managed (with respect to water) fields on a large scale and provide an analysis of the economic tradeoffs associated with these strategies in relation to fertility management.
3. Evaluate the effectiveness of early (fall or early spring) applied P in relation to P availability and rice growth.

Concise General Summary of 2008 Results

Objective 1. To improve N fertilizer guidelines for California rice growers using alternative water management strategies (early season drains).

> In 2008 a replicated field trail was conducted at one site to compare the effects of placement and timing of N fertilizer on rice yields and N uptake in a field that was drained for 11 days for a Clincher application. Yields and N uptake were highest when all of the N was applied as aqua-NH_3. Aqua-NH_3 is applied 3 to 4 inches below the soil surface which helps reduce N losses via denitrification. In treatments were 40 lb N/ac was applied to the surface, applying the surface N after reflooding (following the Clincher application) resulted in higher yields than when the surface N was applied before planting as is the conventional practice.

Objective 2. To test improved N management strategies for conventionally managed (with respect to water) fields on a large scale and provide an analysis of the economic tradeoffs associated with these strategies in relation to fertility management.

> Large scale on-farm studies were conducted in one field in 2007 and in three fields in 2008 to test if applying all the preplant N rate as aqua-NH3 is better than applying both aqua-NH_3 and starter N as is the conventional practice. At the time of this writing yields are not available from one field. In all the other fields the yields from the aqua-NH_3 only strip was higher than the conventional practice. On average, yields in the conventional strip was 9257 lb/ac compared to 9820 lb/ac where all of the N was applied as aqua. These results are almost identical to what we found in the more controlled small plot studies and confirm that starter N fertilizer is not necessary. The difference in cost between aqua NH_3 and ammonium sulfate N is about $0.30. Assuming a growers conventional practice was to apply 40 lb N/ac as starter N. If the grower applied that 40 lb N/ac as aqua-NH_3 instead of starter N, the grower would save $12.00 in material costs alone.

Objective 3. Evaluate the effectiveness of early (fall or early spring) applied P in relation to P availability and rice growth.

In 2008 the applications of P applied in the fall, early spring (before tillage), before planting (conventional practice) and 30 days after seeding (DAS) were evaluated in 9 growers fields. These treatment where compared to a treatment where no P was applied. Unfortunately, there was not a yield response to any of the P treatments indicating that at none of the sites was P limiting. However, an analysis of the P concentrations of the Y leaf sample taken 35 DAS showed that fall applied P, early spring applied P and conventionally applied P treatments all had higher Y-leaf P concentrations than the zero P treatment (the P applied at 30DAS was not analyzed as P was recently applied to this treatment when the 35 DAS samples were taken). This indicates that P availability was greater in these treatments than in eh zero P treatment. Also, the fall applied and early spring applied P had Y-leaf P concentrations similar to the preplant P application which suggests that applying P much earlier still ensures adequate P uptake during the season. In 2009, we will need to verify these results-hopefully on soils which are deficient in P.

Objective 1: To improve N fertilizer guidelines for California rice growers using alternative water management strategies (early season drains).

One of the greatest challenges currently facing California rice growers is the effective management of weeds, which if inadequately controlled can inflict major yield losses and lead to exorbitant herbicide costs. The evolution of herbicide resistant weeds combined with the increased restrictions on herbicide applications is limiting the effectiveness of traditional herbicide and weed control strategies. Consequently, growers are using alternatives which require the use of foliar-active rather than into-the-water applied herbicides. For example, the use of the herbicide "*Clincher*" has been growing in popularity as an effective tool to control early season grasses. This change in early season water management has direct implications for N fertility management. Current N recommendations were developed for continuously flooded rice through the growing season. Though water management involving draining and reflooding events in the early season may expand the range of weed management tools available, the impact these events have on fertility dynamics is not well understood. In theory, an early season drain followed by a flood can lead to significant N losses through nitrification (during the drain) and then denitrification (after reflooding). Although these N transformational processes are well understood in theory, growers have no tangible information on how early season water management affects the N fertility status of their soils and hence on how to improve their fertilizer N management practices.

Field studies were conducted in 2006 and 2007 to help us better understand N dynamics in these systems which will lead us to improved N recommendations. In 2006 and 2007 studies involved closely managed ring studies in which rings were set deep into the soil in fields where an early season drain was taking place. The rings were kept full of water (continuously flooded) to allow us to determine the effect of draining a field. Plant and soil samples were taken regularly through the early season. In 2007 an additional study was conducted in 23 rice fields in the Sacramento Valley region where growers were draining their fields for herbicide applications. In each field, soils were sampled at 2 to 4 day intervals through the drain period and until about 2 weeks after reflooding. Soils were analyzed for extractable NO_3 and NH_4.

A brief summary of results are:

- ✓ In 2006, NO_3 accumulation in the “drained soils” during the drain period ranged from approximately 25 to 31 lb N/ac and in 2007 from 4 to 18 lb N/ac. NO_3 did not accumulate in the “continuously flooded soils”.
- ✓ In 2006 and 2007 total N uptake ranged between was 10 to 20 lb/ac less in the drained than undrained rings. This suggests that draining and reflooding a field results in N losses.
- ✓ In the 2007 regional field study, NO_3 accumulation varied widely between fields from as little as 0.31 lb N/ac to as high as 55 lb N/ac. Averaged across sites the NO_3 concentration increased by 2 lb N/ac/day. Nitrification will be affected by soil moisture, soil properties (texture and carbon) and temperature. The data are being analyzed to better determine the relative effects of each of these factors.

These results clearly indicate the large potential for N losses in rice systems where an early season drain is part of the management. Improved N management practices will likely require changes to the timing or placement of N fertilizer in order to achieve acceptable N use efficiency. This was addressed directly in 2008 through an on-farm field study.

In 2008, a field experiment was conducted on a field between Biggs and Richvale. The experiment was set up as a split plot design with subsurface N treatments being mainplots (Table 1). The subsurface N was applied by the grower as aqua NH_3 to a dept of 3 or 4 inches using a commercial rig. Four rates were evaluated: 0, 80, 120 and 160 lb N/ac. In each main plot, three treatments were evaluated: no surface N, 40 lb N/ac applied to the surface before planting and 40 lb N/ac applied 41 days after sowing. The field was planted on May 13 and drained for a Clincher application on May 18. It was reflooded on May 29. When the soil was reflooded the soil was dry enough to have large cracks. At harvest the plos were sampled for total above ground biomass and yield. Grain and straw samples were analyzed for N in order to determine N uptake in each treatment.

Table 1. Treatments for the field experiment.

Aqua level (lb N/ac)	**0**	**80**	**120**	**160**
	kg N ha^{-1}			
Preplant	0	0	0	0
Preplant	40	40	40	40
Just before reflood	40	40	40	40

*Standard practice aqua rate (specific to grower and field)

When no N was applied yields were 3715 lb/ac and there was a significant response to aqua-NH_3 (Table 2 and Figure 1). The highest yields were over 12,000 lb N/ac in response to and N rate of 160 lb N/ac. There was also a significant response to surface applied N. When surface N was applied preplant, yields increased by about 600 lb/ac. When the surface N was applied in the mid season yields increased by over 1000 lb/ac. These data indicate that the surface N is better utilized when it is applied later in the season. Applying the N before planting to the soil surface may have resulted in significant N losses due to denitirfication.

Table 2. Yield (adjusted to 14% moisture) response to aqua NH_3 rates when no surface N was applied.

Aqua N rate (lb N/ac)	Grain yield (lb/ac)
0	3,715 d
80	9,033 c
120	10,904 b
160	12,095 a

Table 3. Yield (adjusted to 14% moisture) response to surface applied N. There was not a significant interaction between surface and aqua N so results are averaged across main plot treatments.

Surface N rate (lb N/ac)	Grain yield (lb/ac)
0	8937 b
Preplant 40	9554 ab
Mid season 40	9983 a

Figure 1 illustrates that for equivalent N rates, yields and N uptake were always higher when the N was applied as aqua NH_3. These data suggest that the best N management strategy in systems where there is an early season dry down is to apply the N as aqua NH3. Applying fertilizer N deep in the soil helps to protect the N from denitrification losses.

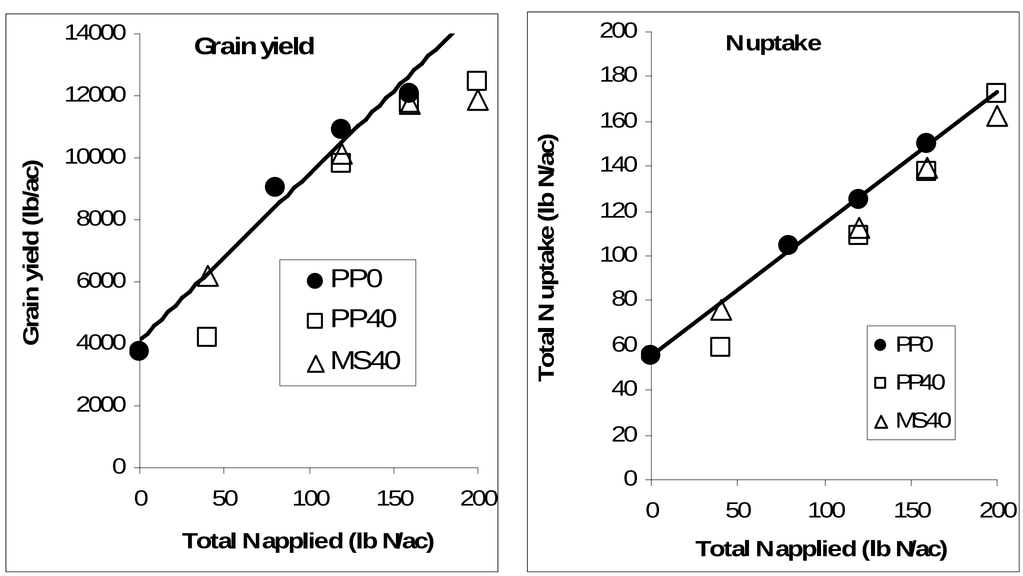

Figure 1. Grain yield (adjusted to 14% moisture) and N uptake as affected by aqua NH_3 and surface N. PPO is no surface N (all aqua NH3), PP40 is 40 lb N applied to the soil surface preplant and MS40 is 40 lb N/ac applied mid season. The linear regression line is for the PPO treatment which received on aqua NH_3.

Objective 2: To test improved N management strategies for conventionally managed (with respect to water) fields on a large scale and provide an analysis of the economic tradeoffs associated with these strategies in relation to fertility management.

Research has been conducted since 2005 to evaluate the necessity of applying starter N (surface applied N applied just before planting). Presumably, starter N improves early season vigor and is necessary to achieve high yields. However, the starter N is applied to the surface and is thus much more subject to losses than the deep placed aqua-N. A summary of our results is as follows:

- ✓ Applying surface N does increase early season biomass in some locations.
- ✓ When equivalent rates of N are applied, yields in the "aqua N only" treatments were higher than when both aqua and starter were applied.

These results are compelling and show that N can be used more efficiently (better N use efficiency and aqua-N is much cheaper than 21-0-0). Furthermore, there is the opportunity to reduce one pass across the field during a busy planting season. This later point would require that growers apply their other nutrients (P and K) during the fall, winter or early spring (before planting). In 2008, we plan to initiate research in this area to evaluate if P applied during this period is as available to the crop as P applied just before planting (see below).

In 2008 we conducted experiments in three grower fields. The experiment included two treatments:

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

Growers used their equipment to apply the fertilizer. In each field growers were asked to applied full length strips of aqua N only using their aqua rigs. The rate that they were to use was to equal the N rate used in the conventional parts of their field and would be the sum of the aqua N and the starter N. At harvest, the grower used a combine equipped with a yield monitor. The grower recorded yield fro the aqua-only strip and an adjacent conventional practice strip. All yields were adjusted to an equivalent moisture.

At the time of writing yields from the Willows field were not available. In all cases the yields from the aqua-N only strip was higher than the conventional practice. On average, yields in the conventional strip was 9257 lb/ac compared to 9820 lb/ac where all of the N was applied as aqua. These results are almost identical to what we found in the more controlled small plot studies and confirm that starter N fertilizer is not necessary.

Table 4. Yields (lb/ac) taken from grower fields where they applied either their conventional practice or the same amount of N all as aqua NH_3.

Grower	Farmer practice		Yields	
location/field	Aqua-N rate	Starter N rate	Aqua+starter	All aqua
Arbuckle (2007)	96	70	9,531	10,001
Arbuckle 1	95	69	9,710	10,040
Arbuckle 2	95	69	8,529	9,419
Willows 1	110	26	Not yet available	

At the time of writing the difference in cost between aqua NH3 and ammonium sulfate N was $0.30. Assuming a growers conventional practice was to apply 40 lb N/ac as starter N. If the grower applied that 40 lb N/ac as aqua-NH_3 instead of starter, the grower would save $12.00 just in material costs.

Objective 3: Evaluate the effectiveness of P fertilizer timing in relation to P availability and rice growth.

Understanding the effects of P timing on P availability is important for a number of reasons. The application of P fertilizer in the fall (or early spring before tillage begins) or up to 30 days after seeding needs to be considered for several reasons. First, algae is a common and increasingly more severe problem for many growers. Algae growth is strongly related to the amount of P in surface waters. Since P is generally applied at or near the soil surface just before flooding, the concentration of P in the flood water can be high. Applying P in the fall would ensure that fertilizer P is mixed with the soil and has had time to adsorb to soil particles. This will lower the P concentration in the surface water. Second, on-going research is showing that surface P applications in the spring encourage weed growth. More weeds germinate and the weeds are larger when surface P is applied. Third, for growers using stale seedbed or minimum-till systems, there is not an option of incorporating the P fertilizer in the spring - it must be applied to the soil surface. In such systems, it would be logical to apply the P in the fall. Fourth, if growers adopt the strategy of applying all N as aqua-N, they can reduce one tractor pass across the field during the busy planting season if they apply their P (and K) in the fall.

Applying P fertilizer in the fall is not a new practice; it is used in the southern rice systems but has not been tested or used widely in California. Similarly in the south they have found that applications of P up to 30 DAS has been as effective as P applied at seeding. The primary issue from a fertility management standpoint is how available is the P is relative to P applied in the spring (the conventional practice).

In 2008 we compared the availability of P applied in the fall or early spring to P applied prior to planting in the conventional manner and P applied 35 days after sowing (DAS). In three minimum-tillage fields and six conventional tillage fields across Glenn, Colusa, Butte and Sutter Counties we collected rice y-leaf samples at 35 DAS and analyzed them for total P and extractable phosphate. We also collected soil samples before P applications and at 35 DAS. In the minimum tillage fields, we analyzed soil samples for plant available soil P according to Olsen, 1982[1]. At harvest we collected a 1m x 1m sample from each plot to determine yield and P uptake. In addition to measuring the availability of P to rice, we recorded the percent weed cover at 35 DAS in the various treatments.

Minimum Tillage Fields

Two of the three minimum-till fields were in Glenn County near Maxwell, and the other was at the RES systems site in Butte County. In our minimum-till fields we imposed the following three treatments in 5m x 5m plots arranged in a randomized complete block with four replications per treatment:

[1] With the following modifications: wet soil, tested the day of sampling; a doubling of soil/extractant dilution factor; and a shaking time of 12 hours.

1) FALL P: Triple Super Phosphate (TSP) applied to the soil surface after straw incorporation in the fall of 2007

2) PREPLANT, SURFACE P: TSP applied to the soil surface immediately prior to flooding and aerial seeding

3) ZERO P: No TSP applied

Table 5. 2008 plant P in rice y-leaf samples and plant available soil P collected at 35 days after sowing (DAS) in minimum tillage fields.

35 days after sowing, 2008 minimum tillage						
	% P Y-leaf		PO4 Y-leaf (ppm)		plant available soil P (mg kg-1)	
FALL P	0.36	A	1099	A	0.37	A
PREPLANT, SURFACE P	0.35	AB	1052	A	0.30	A
ZERO P	0.33	B	861	B	0.24	A
A, B separation indicates significant differences (p<0.05, REGWQ)						

Tissue analyses of rice y-leaf samples taken at 35 days after sowing (DAS) indicate that plant P is not significantly different in the FALL P and the PREPLANT, SURFACE P treatments (Table 5). FALL P has significantly higher tissue P than ZERO P. None of the treatments have plant P values below established critical levels. This indicates that P applied in the fall is as available as P that is applied preplant. Though differences in plant available soil P at 35 DAS are not significant between treatments, they follow the same trends as the plant P data from 35 DAS[2].

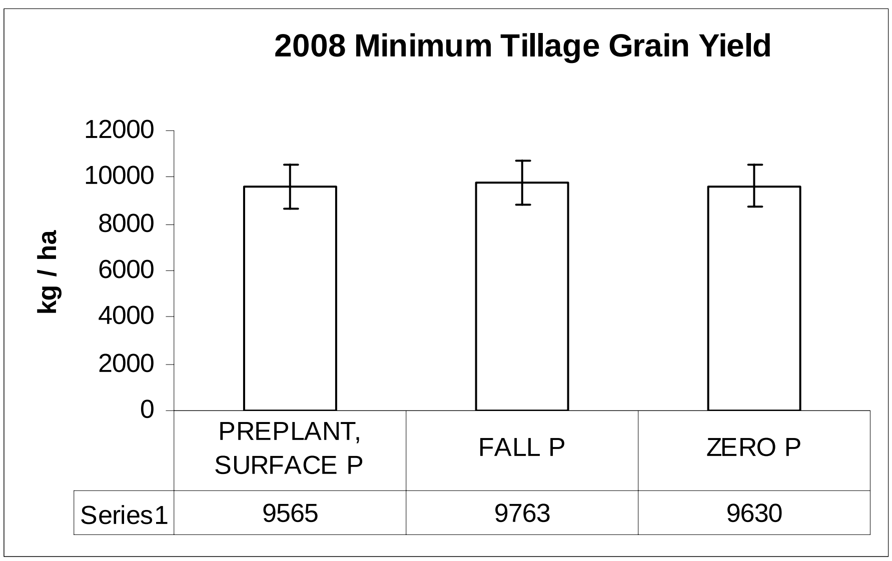

Figure 2. 2008 grain yields (kg/ha adjusted to 14% moisture) by treatment in minimum tillage fields. Differences are not significant (p=0.79).

[2] Two of three minimum-till fields plant available soil P reported. RES systems site was eliminated due to extreme between-replication soil P variability both at pre-fertilization and 35 DAS sampling times.

There were no significant differences in yield between P treatments (Fig. 2). The rice in the minimum-tillage fields did not appear to be P limited as indicated both by a lack of yield response to P fertilization and by high initial Olsen P values (14.1-19.1 mg/kg P). Based on the data from 35 DAS and harvest, we conclude that in the minimum-tillage fields P fertilizer applied in the fall was as available to the rice plant as P applied prior to planting in the conventional manner.

Availability of Fall, Early Spring, and Late (35 DAS) P applications

In addition to the comparisons made in the three minimum tillage fields, we compared the availability of P applied in the fall or early spring (Early P) to P applied in the conventional manner in five conventionally tilled fields in Colusa, Sutter, and Butte counties. In the conventionally tilled fields we added another alternative P timing treatment: P applied 35 days after sowing (DAS).

Because spring tillage events occurred after the fall or early spring P applications in the conventionally tilled fields, we were unable to randomize a Zero P treatment with the Early P treatment. As a result, we had growers skip a large area of the field during their fall and early P applications. We set up a randomized complete block in these skipped areas, where the grower had not applied any P, and another in a nearby area where the grower had applied P early in the season. In both blocks we imposed 4 replications of the following three treatments in 5m x 5m plots:

1) PREPLANT, SURFACE P: TSP applied to the soil surface immediately prior to flooding and aerial seeding

2) ZERO P: No TSP applied

3) 35 DAS P: TSP applied 35 days after sowing

In the blocks where P fertilizer had been applied in the fall or early in the spring, the plots with no TSP added were the EARLY P treatment. In blocks where no P fertilizer had been applied by the grower, the plots with no TSP added were the ZERO P treatment. The randomization for this design only allowed statistical comparison between the treatments within the same block. Therefore, we compared the EARLY P and ZERO P treatment means to PREPLANT, SURFACE P treatment means obtained independently, in separate blocks

Table 2. 2008 plant P in rice y-leaf samples at 35 DAS, weed cover at 35 DAS, and yield (adjusted to 14%) at harvest.

Management (Field Scale)	Treatment (Plot Scale)	**%P Y-leaf**	p value	**PO4 Y-leaf (ppm)**	p value	**Weed Cover (%)**	p value	**Yield (kg/ha)**	p value
EARLY P	**PREPLANT, SURFACE P**	0.33	0.10	1135	0.04	16.0	0.002	11796	0.67
	EARLY P (fall or early spring)	0.32		1070		12.8		11727	
ZERO P	**PREPLANT, SURFACE P**	0.32	<0.0001	1119	<0.0001	19.1	0.0002	11133	0.16
	ZERO P	0.29		935		13.3		11405	

In general P concentrations in the Y-leaf at 35 DAS were lower for EARLY P compared to PREPLANT, SURFACE P. And PREPLANT, SURFACE P had higher Y leaf P concentrations than the ZERO P treatment. Both the EARLY P and ZERO P treatments had significantly less weed cover than their respective PREPLANT, SURFACE P treatments ($p=0.002$; $p=0.0002$, respectively). There were no significant differences in grain yields between any of the treatments at harvest.

Because TSP was applied 35 days after sowing in the 35 DAS P treatment, we only collected harvest data for this treatment. In the conventionally tilled fields where we applied TSP 35 DAS, the grain yield was 12258 kg/ha, which was not significantly different than the 11917 kg/ha grain yield for the PREPLANT, SURFACE P treatment in the same fields. The grain and plant P for the harvest samples are still in process and should further clarify whether or not P was less available to the rice plant as a result of changes in the timing of P fertilization.

In summary, changing the timing of P fertilizer application to either before spring tillage or to 35 days after sowing (DAS) had no effect on grain yields as compared to the conventional preplant, surface application of P fertilizer. We should note that none of the fields in this study demonstrated a significant yield response to P fertilization. Because P did not appear to be limiting in the fields we studied, it is important to examine whether changing the timing of P fertilization will affect the availability of P to the rice plant in fields where P might be limiting. In 2009 we intend to examine these same P fertilization timing alternatives on fields that have demonstrated a yield response to P fertilization in the past. That said, this years data do suggest that P applied in the Fall or early spring is plant available based on Y-leaf P concentrations taken early in the season.

Oral Presentation:

B. Linquist, K. Koffler, M. Ruark, M. Lundy, J. Hill and C. van Kessel. 2008. Improving fertilizer management recommendations for California's changing rice growing environment. Annual winter grower meetings. January 25 Yuba City and Colusa; January 29 Richvale and Glenn.

B. Linquist, K. Koffler, M. Ruark, M. Lundy, J. Hill and C. van Kessel. 2008. Improving fertilizer management recommendations for California's changing rice growing environment. PCA meeting March 13, 2008, Gridley, CA

Linquist, B.A., M. Lundy, M. Ruark, K. Koffler, and C. van Kessel. 2008. Nutrient management challenges with changing water management practices in California rice systems. *Rice Technical Working Group Meeting.* February 18-21. San Diego, CA

Lundy, M, A. Fischer, C. van Kessel, M. Ruark, J. Hill, D. Spencer, R. Mutters, C. Greer, B. Linquist. 2008. "The Effect of Phosphorus Fertilizer Placement on Weed and Algae Growth in Rice Systems." *2008 Joint Annual Meeting of The Geological Society of America, Soil Science Society of America, American Society of Agronomy, Crop Science Society of America, and Gulf Coast Association of Geological Society.* Houston, Texas, 5-9 October, 2008.

B. Linquist. 2008. Improving fertilizer guidelines for California's changing rice climate. CAPCA meeting Dec 10, 2008, Colusa, CA

Poster Presentations:

Lundy, M, A. Fischer, C. van Kessel, M. Ruark, J. Hill, D. Spencer, R. Mutters, C. Greer, B. Linquist. 2008. "Timing and Placement Effects of Phosphorus Fertilizer on Weed Growth in California Rice Systems." *2008 Rice Field Day* California Cooperative Rice Research Foundation, Inc., University of California, USDA. Rice Experiment Station, Biggs, CA, 27 August, 2008.

Lundy, M, A. Fischer, C. van Kessel, M. Ruark, J. Hill, D. Spencer, R. Mutters, C. Greer, B. Linquist. 2008. The Effect of Phosphorus Fertilizer Placement on Weed and Algae Growth in Rice Systems. *Rice Technical Working Group Meeting.* February 18-21. San Diego, CA