**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE**
**FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)**

# Final Report

## Project Title: Fertility Management in Rice


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## Executive Summary

This report summarizes three years of research to improve fertility management in California rice systems. We had two primary tasks: (1) to evaluate current starter fertilizer recommendations for flooded rice soils and (2) to improve critical N, P and K guidelines for mid-season tissue. With respect to these two objectives we can make the following recommendations.

1. Our research showed limited to no benefit to the application of starter N fertilizer. Farmers typically apply 30 to 50 kg N/ha as starter to their rice fields in addition to the 100 to 150 kg aqua N/ha. Our findings indicate that in some cases early season vigor was enhanced by the addition of starter N, however in no case did starter N result in higher yields. Also, N recovery efficiency was higher for aqua-N than it was for starter N. This can have tremendous cost savings to growers. First, growers could apply all of their N as aqua instead of the more costly starter N fertilizers. In Dec 2007 aqua-N cost about $0.41/lb N compared to $0.71/lb for ammonium sulfate (21-0-0). Second, growers could plant a few days earlier as they would be able to eliminate one tractor pass across a field. This would allow for savings in time as well as costly field operations.
2. For P fertilizer management, results from 73 fields showed that there was a significant response to P fertilizer at only 5 sites, although at about 1/3 of the sites there was an early season visual response. This suggests that growers are generally over applying their P fertilizer and P has built up in the soil over time to the point that there is no longer a response. The problem is that the currently used soil test is not a great indicator of P deficiency. If a soil is below the critical limit of 6 mg/kg there is a good chance for a P response. However, if the soil is above this value we still observed significant responses to P. Our recommendation to growers is to apply the amount of P they are removing from the field in grain (and straw if they remove it). We are working at identifying a better soil test in the mean time.
3. We did not do any field studies related to K fertilizer management, except in 2005. In 2005, we did not identify any K deficient soils. Currently, K deficiency is a problem in the red rice soils on the east side of the Sacramento Valley. Our studies focused on fine-tuning current K recommendations based on how much K is lost in irrigation water. Our findings indicate that irrigation waters originating from the Yuba River are low in K - containing about 0.5 ppm K. It is these waters that are used for irrigating the red soils mentioned above. All of the other surface irrigation water contains double the amount of K (1.0 ppm K). Some growers flood their fields in the winter and let water run through their fields during the winter period. This practice can result in significant K losses.
4. We were not able to identify improved mid-season tissue tests for either N or P that would assist growers in making better-informed decisions on whether or not to apply additional fertilizer at mid-season. For N management we suggest continuing to follow the current

recommendations.  For P fertilizer, if the crop is deficient, the P needs to be applied before planting; applying the P mid-season will not help much.

## OBJECTIVES (TASKS)

1. **To evaluate current starter fertilizer recommendations for flooded rice soils.**
2. **To improve critical N, P and K guidelines for mid-season tissue.**

## METHODOLOGY

The methodology used in this study differed from what was written in the original proposal. Given the 2005 results, it was necessary to modify Years 2 and 3 tasks because we did not identify P or K deficient sites to set up a P and K rate trials as intended in the original proposal. Modifications were designed in the general spirit of the initial proposal. In summary, N trials were established as per proposal. For P, we set up on-farm trials in 15 fields in 2006 and 53 fields in 2007 to identify P limiting sites and to better understand what makes a site P limiting. For K, we attempted to fine-tune the K recommendations for rice by evaluating the nutrient input/output budget more closely-specifically the contribution of irrigation water to K supply and the amount of K leaving the rice field in the field drain water. These changes were indicated in the 2006 Annual Report.

**Task 1: To evaluate current starter fertilizer recommendations for flooded rice soils.**
Subtask 1.1: Selection of field sites.

*Nitrogen recommendations*

In 2005, N, P and K fertility trails were conducted at 5 locations. In 2006, N fertility trails were conducted in four locations and in 2007 in three locations (Table 1 and 2).

Table 1. Crop management details for each of the study sites.

| Site | Cropping system | Previous years straw mgmt | Variety | Planting date | Aqua –N rate (kg/ha) | Top-dress N (kg/ha) | Early season water mgmt. |
|---|---|---|---|---|---|---|---|
| Arbuckle-Incorp (2005) | Rotate with other crops | Straw incorp (spring) 2 yr. | M202 | May 1 | 112 | 0 | Leathers* |
| Sheridan (2005)[a] | Continuous rice | Straw incorp (fall) 10 yr | M202 | May 6 | 148 | 24 | Drained (3wks)** |
| Princeton (2005) | Continuous rice | Straw incorp fall) 3 yr | M205 | May 11 | 159 | 0 | Flooded |
| Gridley (2005) | Continuous rice | Straw incorp (fall) 10 yr | M206 | May 26 | 107 | 0 | Flooded |
| Richvale (2005)[b] | Continuous rice | Straw incorp (fall) 15 yr | M202 | June 3 | 118 | 0 | Flooded |
| Arbuckle -Incorp (2006) | Rotate with other crops | Straw incorp (spring) | M206 | May 12 | 101 | 0 | Leathers |
| Arbuckle -Burn (2006)[c] | Rotate with other crops | Straw burn | M206 | May 13 | 101 | 0 | Leathers |
| Sheridan (2006)[a] | Continuous rice | Straw incorp (fall) 11 yr | M202 | May 23 | 126 | 47 | Drained (3 wks) |
| Richvale (2006)[b] | Continuous rice | Straw incorp (fall) 15 yr | M206 | June 2 | 112 | 0 | Drained (1 wk) |
| Arbuckle -Incorp (2007) | Rotate with other crops | Straw incorp (spring) | | April 27 | 101 | 0 | Leathers |
| Arbuckle -Burn (2007)[c] | Rotate with other crops | Straw burn | | April 28 | 108 | 0 | Leathers |
| Biggs (2007) | Continuous rice | Straw incorp (fall) 15 yr | M206 | April 24 | 140 | 0 | Flooded |

*Leathers method refers to the practice of draining the field shortly after water seeding for a period of 3 to 7 days. This allows the young seedling to root in the soil, preventing young seedling from floating and being blown by the wind.
** The number in "()" refers to the period of drain.

Table 2. Soil properties of each site of the N study

| Site | Year | pH | Total N | OM | Olsen-P | Ex-K | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|
| | | | % | % | ppm | ppm | % | % | % |
| Arbuckle-1* | 2005 | 6.3 | 0.16 | 2.53 | 3.9 | 190 | 10 | 36 | 54 |
| Sheridan-1 | 2005 | 5.2 | 0.10 | 1.89 | 18.5 | 97 | 41 | 39 | 20 |
| Princeton | 2005 | 5.5 | 0.20 | 3.86 | 4.7 | 144 | 10 | 53 | 37 |
| Gridley | 2005 | 5.7 | 0.17 | 2.31 | 4.1 | 151 | 19 | 28 | 53 |
| Richvale-1 | 2005 | 5.2 | 0.16 | 2.24 | 9.4 | 190 | 20 | 30 | 50 |
| Arbuckle-2 | 2006 | 6.4 | 0.18 | 2.37 | 6.6 | 177 | 9 | 35 | 56 |
| Arbuckle-3 | 2006 | 6.4 | 0.15 | 2.37 | 14.2 | 183 | 10 | 35 | 55 |
| Sheridan-1 | 2006 | 5.1 | 0.09 | 1.59 | 14.6 | 83 | 43 | 37 | 20 |
| Richvale-1 | 2006 | 6.4 | 0.14 | 1.74 | 5.9 | 155 | 18 | 29 | 53 |
| Arbuckle-4 | 2007 | 6.7 | 0.16 | 2.33 | 10.8 | na | 5 | 41 | 54 |
| Arbuckle-3 | 2007 | 6.6 | 0.18 | 2.60 | 9.2 | na | 8 | 39 | 53 |
| Biggs | 2007 | 5.3 | 0.17 | 2.40 | 2.2 | na | 12 | 25 | 63 |

*Sites with the same number following them indicate that the experiments were conducted in the same field but in a different portion of the field

*P recommendations (2006 and 2007)*

In 2005 there were no significant responses to P fertilizer at the five locations selected. Therefore, in 2006 and 2007, experiments were conducted across a much broader range of soils and regions in order to identify P deficient soils. In 2006, 15 fields were selected and 53 sites in 2007 (Table 1-Appendix). At each location there were two treatments (0P and +P)

*K recommendations (2006 and 2007)*

In order to better refine K recommendations for California rice growers, we analyzed irrigation and rice field outlet water for K. This will allow us to know how much K is being provided by irrigation water and how much K is potentially lost from the field when water is released from the bottom of the field. Ten fields were selected from around the valley for the study (Table 3). Fields varied in their straw and water management.

Table 3. Site descriptions of the sites where K budgets were monitored in the field inlet and outlet waters.

| Site # | Site Name | Year | Straw Mgt. | Variety | Aqua Rate | Starter Fertilizer Rate N | P | K |
|---|---|---|---|---|---|---|---|---|
| | | | | | | kg ha$^{-1}$ | | |
| 1 | Marysville(1) | 2006,2007 | Incorp, Burn | Koshi | 0 | 34 | 28 | 54 |
| 2 | Marysville(2) | 2006 | Burn | Koshi | 0 | 34 | 28 | 54 |
| 3 | Marysville(3) | 2007 | Incorp | Koshi | 0 | 34 | 28 | 54 |
| 4 | Richvale(1) | 2006,2007 | Burn | M205 | 135 | 50 | 17 | 25 |
| 5 | Richvale(2) | 2006,2007 | Incorp | M205 | 135 | 50 | 17 | 25 |
| 6 | Arbuckle(1) | 2006,2007 | Burn | M206 | 108 | 70 | 0 | 0 |
| 7 | Arbuckle(2) | 2006 | Incorp | M202 | 100 | 70 | 0 | 0 |
| 8 | Arbuckle(3) | 2007 | Incorp | M202 | 100 | 70 | 0 | 0 |
| 9 | Willows(1) | 2006,2007 | Burn | M205 | 100 | 9 | 17 | 32 |
| 10 | Willows(2) | 2006,2007 | Incorp | M205 | 100 | 9 | 17 | 32 |

Subtask 1.2: Plot layout, experimental design and sampling scheme

In 2005, 8 fertilizer treatments were evaluated in a randomized complete block design (Table 4). At each site these treatments were replicated five times. Efforts were made to have each replication in different checks, however, at two locations (both in Butte county) all replications had to be in a single check to facilitate farmer field operations. The two growers in Butte County applied starter fertilizer by air requiring us to have all five blocks in a single check.

Table 4. Treatments and design

| Treatment # | Basal Aqua N | Starter Fertilizer | Plot type | $^{15}N$ plot included as part of main trt |
|---|---|---|---|---|
| 1 | 0 | -PK | Main | |
| 2 | Yes | --- | Main | |
| 3 | Yes | N-- | Inside #2 | Yes |
| 4 | 0 | NPK | Inside #1 | |
| 5 | Yes | NPK | Main | Yes |
| 6 | Yes | -PK | Main | |
| 7 | Yes | N-K | Main | |
| 8 | Yes | NP- | Main | |

Starter fertilizer rates will be: N (30), $P_2O_5$ (50), $K_2O$ (50). Aqua-N will be as per grower.
Sources: N (ammonium sulfate), P (TSP) and K (Potassium sulfate)

Plot size varied by site to account for differences in equipment width (fertilizer applicators and harvesters). Plot length ranged from 125 ft to 200 ft. A single replication showing the layout of the eight treatments is shown in Figure 1. Treatment details are shown in Table 2 (Note: additional treatments were added to those of the original proposal to help us better understand the benefits of starter N fertilizer). The rational for the treatments are as follows:

- ✓ TRT 5-8 is a simple nutrient omission trial to identify what nutrients are limiting. Nutrient limitations will be determined on the basis of plant biomass and yield.
- ✓ TRT 1 is a control and gives us the indigenous N supply. From this we can measure the benefit (and efficiency) of fertilizer N of the other treatments.
- ✓ TRT 2 is a control. We can use this to measure fertilizer use efficiency of starter fertilizer (by mass balance).
- ✓ When the growth and N uptake curves of 1 and 2 and of 4 and 5 diverge this will determine when the crop under starter and no start has reached the aqua-N.
- ✓ Treatment 5 with the $^{15}N$, we will be able to determine the contribution of the starter to the total N uptake as well as determine N use efficiency. Comparison of this with the $^{15}N$ in treatment 3 will indicate if P and K improve N use efficiency.

Every effort was made to apply the starter fertilizer as the farmer would. In all cases it was surface applied.

Soils were sampled from each replication after the fields were planed. These were dried and analyzed (Table 3). At 3 and 4 weeks after sowing, whole plant samples were taken from treatments 1, 2, 4, 5 and 6. These plants were analyzed for above ground biomass and nutrient content. Data from these samples will be used for the determination of starter N fertilizer uptake efficiency. Five weeks after sowing (mid-tillering) plant samples were taken for above ground biomass from all treatments. Also, at this time, soil and plant samples were taken from the $^{15}N$ plots. At harvest, crop cuts were taken from each experimental plot. Plant and soil samples were also taken from $^{15}N$ plots. Harvesting was completed on Oct 18, 2005. Total above ground biomass and grain yields were determined.

In 2006 and 2007, an experiment was conducted in seven grower fields (4 in 2006 and 3 in 2007). The primary objective of this experiment was to determine the correct rates of starter and aqua-N fertilizer. The experiment was set up as a split-plot design, with three replications in each field. The main-plot was the aqua-N treatment and sub-plot was starter-N treatment (Table 5). There were five aqua-N treatments based on the grower standard practice (SP) (0, SP-30, SP, SP+30 and SP+60). The subplot N treatments were applied after the aqua-N to the soil surface and consisted of three rates: 0, 30 and 60 kg N/ha.

Table 5. Preplant N treatments used in the 2006 and 2007 experiments. Main plots are injected aqua-N and subplots are surface applied N. The standard practice aqua-N rate (SPA) varied at each site and was what the grower conventionally used.

| | Aqua-N (kg ha$^{-1}$) | Surface N (kg ha$^{-1}$) | Total preplant N (assuming SPA aqua-N is 110) (kg ha$^{-1}$) |
|---|---|---|---|
| 1 | 0 | 0, 30, 60 | 0, 30, 60 |
| 2 | SPA - 34 | 0, 30, 60 | 76, 106, 136 |
| 3 | SPA | 0, 30, 60 | 110, 140, 170 |
| 4 | SPA + 34 | 0, 30, 60 | 144, 174, 204 |
| 5 | SPA + 72 | 0, 30, 60 | 182, 212, 242 |

Soils were sampled from each field before N was applied. Twice, between 2 and 4 weeks after sowing, whole plant samples were taken from six of the treatments. These plants were weighed for above ground biomass and were analyzed for N content. At five weeks after sowing (mid-tillering) plant samples were taken for above ground biomass determination of all treatments. At harvest all plots were harvested for grain yield and total above ground biomass. Grain and straw samples were analyzed for N content in order to determine crop N uptake and to allow for calculation of fertilizer uptake efficiency.

*P recommendations (2006 and 2007)*

In 2006, experimental plots were established in 15 grower fields and in 2007, experimental plots were established in 53 grower fields. Field sites were selected to span geographic regions, straw managements, and cropping

histories. Detailed grower histories including rice variety, seeding practice, tillage practice(s), straw management, and water management were accumulated. At each grower site, the experimental plots were established in representative areas of the field, not near borders. The experimental plots were in total 13.2 x 3.3 m (16.5 $m^2$), which includes 6 separate plots 2.2 x 3.3 m. In most cases plots were established after the grower applied aqua ammonium. If the grower applied starter fertilizer aerially, the experimental site was covered with a tarp to prevent fertilizer from landing on the soil. If the grower applied liquid starter fertilizer, then we had the grower not apply the fertilizer in an area larger than the experimental site. All fields were rolled prior to application of our fertilizer treatments. The experimental design was a randomized complete block design with three replicates. There were two treatments: no application of P fertilizer and application of 40 kg-P $ha^{-1}$. Additional starter N and K were applied to all plots at a rate of 40 kg-N $ha^{-1}$ and
50 kg $ha^{-1}$ to ensure these macronutrients were non-limiting.

Soil samples were taken prior to starter fertilizer application. Samples were ground, passed through a 4 mm sieve, and analyzed for Olsen-P, Bray-P, total N, total C, organic matter concentration, pH, CEC, exchangeable-K, and texture by DANR laboratories. Harvest samples were taken from each plot from an area of 0.6 $m^2$; samples were weighted and subsampled in the field immediately after harvest. Subsamples were oven dried, and grains were separated from the straw biomass. Grain and straw were ball milled and sent to DANR to be analyzed for total P.

*K recommendations (2006 and 2007)*

In 2006, four grower sites were selected (10 fields). At each grower site, two fields were selected for the study, one field burned the straw after harvest and one field incorporated the straw. The outlet of each field was fitted with a square notch weir and a data logger to monitor outflow rates. Samples were collected throughout the growing season and winter flooding season and analyzed for potassium concentration by DANR. Samples were also collected from inlet canals, although no inflow measurements could be made. Samples were collected during the growing season of 2006, the winter flooding beginning in November of 2006, the growing season of 2007, and the winter flooding beginning in November of 2007.

Subtask 1.3: Crop evaluation and nutrient uptake determination.

*N recommendations*

At harvest, whole plant samples were taken from each plot. Samples were divided into grain and straw fractions for determination of total above ground biomass and grain yield. Samples were ground and analyzed for N content and to determine N uptake from each fertility treatment.

*P recommendations (2006 and 2007)*

At harvest, whole plant samples were taken from each plot. Samples were divided into grain and straw fractions for determination of total above ground biomass and grain yield. Samples were ground and analyzed for P content and to determine P uptake from each P fertility treatment.

*K recommendations (2006 and 2007)*
This was not done – see earlier explanation.

Subtask 1.4: Analysis of actual and projected costs and benefits.
From this study, we can conduct an analysis of the benefits of apply aqua versus starter N fertilizer. We have taken a very simple approach to this based on the difference in cost of aqua vs starter N fertilizer. Results from the K study allow for a determination of how much K is being lost in surface waters. The cost of this was calculated by estimating the cost to apply that amount of nutrient. Results from the P study do not lend themselves to an economic analysis. Our findings are not conclusive and do not allow farmers to avoid applying P fertilizer.

Subtask 1.5: Extension of results.
Results from this research have been presented at the annual winter rice growers meetings in 2006, 2007 and 2008. These meetings usually attract 200 to 300 growers each year. Each year we have also presented results from this research to PCA's involved with rice production. Additionally, results have been presented each year at the Rice Field Day in Biggs, CA. Results are currently being used to update a UCCE publication called "Rice Nutrient Management in California". There has been considerable interest from growers in this research due to the cost-saving benefits of applying all of their N as aqua. Aqua is a cheaper source of N, it can be placed deeper in the soil where it is better protected from loss, and skipping the starter N application may allow growers to have one less pass over their fields during a busy planting season. This research will be further published in California Agriculture and other refereed journals.

**Task 2: To improve critical nutrient guidelines for mid-season tissue samples.**

Subtask 2.1: Mid-season tissue sampling and analysis.
*N recommendations*
Whole shoot samples were taken from each treatment at 35 DAS. These samples were dried, weighed, ground and analyzed for total N.
*P recommendations (2006 and 2007)*
Flag leaf samples were taken at mid tillering (35 DAS), 10 per plot, ball milled and analyzed for total P and extractable P concentration.
*K recommendations (2006 and 2007)*
No mid-season leaf samples were analyzed as we did not identify K deficient sites.

Subtask 2.2: Extension of results.

Results from this research have been presented at the annual winter rice growers meetings in 2006, 2007 and 2008. These meetings usually attract 200 to 300 growers each year. Each year we have also presented results from this research to PCA's involved with rice production. Additionally, results have been presented each year at the Rice Field Day in Biggs, CA. Results are currently being used to update a UCCE publication called "Rice Nutrient Management in California". There has been considerable interest from growers in this research due to the cost-saving benefits of applying all of their N as aqua. Aqua is a cheaper source of N, it can be placed deeper in the soil where it is better protected from loss, and skipping the starter N application may allow growers to have one less pass over their fields during a busy planting season. This research will be further published in California Agriculture and other refereed journals.

## RESULTS

Results for 2005 (the first year of the study) will be presented first. Results for 2006 and 2007 will be presented by nutrient (N, P and K).

### Results for 2005

2005 was not a favorable year for rice production in California, the season was marked by a wet and cool May, which delayed field operations, planting and rice growth. July was unusually hot and during harvest it was cool and harvest was delayed due to an absence of north winds. Given the unusual year, the data presented (Table 2-Appendix) below need to be taken with caution.

In general, all of the sites responded to both aqua and starter N fertilizer treatments. This is as expected as N is usually the most limiting nutrient in rice systems. Based on grain yield data, none of the sites was either P or K deficient. At one site (Gridley) there appeared to be an early season P deficiency, however, at the end of the season yields were actually higher in the no P treatment. The reasons for this are unclear. In relation to N and starter fertilizer applications a number of specific comments can be made:

1. There is a benefit to applying a complete starter (NPK) application. At all sites and early season sample times above ground biomass yield was significantly higher when there was a NPK starter application (T5) than when no starter was applied (T2). However, by harvest yields at only two of the sites (Arbuckle and Richvale) were significantly higher due to a complete starter application.
2. At all sites there was a benefit to the application of starter N (comparison of T5 and T6). Where starter N was applied biomass was higher at sample time 1 (2 sites significant) and times 2 and 3 (4 sites significant). Again, by harvest the benefit of starter N was only apparent in the grain yields of two sites (Arbuckle and Richvale).

3. Based on the early season biomass data the crop starts taking up the basal applied aqua N sometime before the first sampling date. A comparison of T1 and T6 shows that biomass was higher (significantly at 3 sites) where there was aqua-N.
4. Grain yields when no N was applied ranged from 3074 to 6940 kg/ha and reflects the amount and availability of soil indigenous N. It was highest at the Richvale site where straw has been incorporated for over 10 consecutive years. The lowest was at the Sheridan site where the soils were coarser textured but also where there was an early season drain, which may have resulted in significant denitrification losses.
5. The efficiency of starter applied N varied widely between sites and ranged from 3 to 57 kg/kg (Table 5). Low starter N use efficiency at the Princeton site is most likely due to rainfall immediately after starter N application but several days before flooding. This allows the N to nitrify before flooding and when the field becomes flooded the nitrate denitrifies.
6. The efficiency of aqua-N was relatively similar across sites ranging from 34 to 43 kg/kg. It was lowest at the Richvale site perhaps due to the high yields achieved in the 0N treatment.

**Nitrogen fertility management – results for 2006 and 2007**

Early season results (Table 3 and 4 – Appendix)

1. At sites where the first plant samples were taken 13 days after sowing (DAS) or later, the data support the hypothesis that the plant had access to the aqua-N applied 3 to 4" deep in the soil at this very early stage (Table 6). This supports data from 2005.
2. Applying starter N to the soil surface generally increased biomass regardless of the aqua-N rate. In all cases, by mid-tillering there was a significant aqua-N by starter-N interaction suggesting that at the response to starter N differed for different aqua-N treatments. In general, the greatest response to starter N was when no aqua-N was applied. As aqua-N rates increased there was less of a response to starter-N.
3. At half of the sites, applying both starter and aqua-N resulted in increased vigor (measured at 35 days after sowing). At the other sites there was no difference in early season vigor.
4. Mid-season tissue analysis of the whole shoot shows that there was a significant relationship between N concentration and final yield. However, this relationship was only useful for each site individually. When all of the sites were combined there was not a clear "critical" level to determine if more N fertilizer should be applied or not.

Table 6. Whole shoot percent N and N uptake of plant samples taken on the first sample time at each site. The "0N" samples were taken from the control where no N was applied. The "All aqua" treatment was taken from the standard aqua rate in 2005 and the standard aqua rate plus 60 (SP+60) in 2006 and 2007.

| | | | N (%) | | N uptake (kg N/ha) | |
|---|---|---|---|---|---|---|
| Site | Year | DAS[1] | 0N | All Aqua | 0N | All Aqua |
| Arbuckle-1 | 2005 | 22 | 2.40 | 2.73* | 0.71 | 0.91* |
| Sheridan-1 | 2005 | 26 | 2.94 | 3.15 | 5.59 | 7.20* |
| Princeton | 2005 | 22 | 2.76 | 3.31* | 3.30 | 5.46* |
| Gridley | 2005 | 21 | 3.06 | 3.66* | 4.16 | 6.68* |
| Richvale-1 | 2005 | 20 | 3.27 | 3.62* | 2.27 | 2.76* |
| Arbuckle-2 | 2006 | 19 | 2.76 | 3.51* | 3.58 | 5.32* |
| Arbuckle-3 | 2006 | 20 | 3.12 | 3.58 | 3.73 | 4.85 |
| Sheridan-1 | 2006 | 14 | 3.15 | 3.30 | 1.44 | 1.48 |
| Richvale-1 | 2006 | 17 | 3.91 | 4.18* | 4.44 | 5.48* |
| Arbuckle-4 | 2007 | 14 | 2.22 | 3.02* | 0.63 | 0.94* |
| Arbuckle-3 | 2007 | 13 | 2.39 | 2.87* | 0.49 | 0.68* |
| Biggs | 2007 | 14 | 3.16 | 3.37* | 0.79 | 0.83 |

[1] DAS = days after sowing

* Indicates a significant difference ($P < 0.05$) between the 0N and All Aqua treatment.

Yield results

1. In the N study, all sites responded to N fertilizer additions and at all sites maximum yields were between 6 and 14 t/ha (Figure 1). The lower yields in the Arbuckle (straw incorporated site) are possibly due to two factors. First, the straw was left on the surface over the winter. It was neither incorporated nor flooded. This resulted in a lot of fresh straw at the beginning of the growing season, which may have tied up fertilizer N. Second, the aqua N was applied about 1 week before the field was flooded possibly leading to N losses.
2. In ALL cases, the yield achieved for the same amount of N was higher (or the same) when all of the preseason N was applied as aqua (Figure 1).
3. Where possible to determine, higher yields and greater N efficiency was possible if all of the N was applied as aqua.
4. These data suggest that there is no benefit from the surface application of starter N. All of the N can be applied in the aqua form. This may allow growers to eliminate a pass over their fields during the busy planting season.

Fertilizer movement in the soil profile

In 2007, soil samples were taken from each of the field experiments to determine the extent of N fertilizer movement in the soil profile. Soil samples were taken from 0-5 cm and from 5-15 cm and analyzed for extractable N. The analysis shows that the fertilizer N remained where it was applied in the soil profile. That is the starter fertilizer remained on the surface and the deeper placed aqua-N was only found in the 5-15 cm depths (Figure 2). This indicates that the young rice roots grew down to the aqua very quickly early in the season as opposed to the aqua-N moving upwards in the soil profile.

Is urea better than 21-0-0 for starter N?

1. In 2007, we did one test where the standard aqua practice of the grower was compared to a starter N rate of 60 kg/ha using either urea or 21-0-0. The results are not conclusive.
2. At mid-tillering 21-0-0 resulted in slightly higher greater biomass at the Richvale site. At the Arbuckle sites the biomass was similar between the two sources of N fertilizer.
3. Yield results show that the two sources of fertilizer resulted in similar yields at all sites except the Arbuckle – burn site. At this site urea produced higher yields than 21-0-0.

Nitrogen recovery efficiency

1. Overall N recovery efficiency averaged 52% (Table 7).
2. N recovery efficiency was higher for aqua-N than for starter N. Applying N all as aqua resulted in an average N recovery efficiency of 53% compared to 51% if the total N rate was split between aqua and starter N.

Table 7. Nitrogen recovery efficiency at each site.

| | | SP-30 | | | SP | | | SP+30 | | | SP+60 | | | Site |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Year | 0 | 30 | 60 | 0 | 30 | 60 | 0 | 30 | 60 | 0 | 30 | 60 | Mean |
| Arbuckle-1 | 2005 | | | | 45 | 52 | | | | | | | | **49** |
| Sheridan-1 | 2005 | | | | 44 | 46 | | | | | | | | **45** |
| Princeton | 2005 | | | | 73 | 63 | | | | | | | | **68** |
| Gridley | 2005 | | | | 48 | 43 | | | | | | | | **46** |
| Richvale-1 | 2005 | | | | 56 | 65 | | | | | | | | **61** |
| Arbuckle-2 | 2006 | 45 | 42 | 58 | 51 | 47 | 51 | 50 | 48 | 51 | 53 | 63 | 61 | **52** |
| Arbuckle-3 | 2006 | 52 | 57 | 64 | 64 | 70 | 61 | 64 | 60 | 67 | 65 | 72 | 67 | **64** |
| Sheridan-1 | 2006 | 57 | 54 | 51 | 60 | 53 | 53 | 60 | 58 | 55 | 50 | 56 | 52 | **55** |
| Richvale-1 | 2006 | 82 | 68 | 57 | 79 | 65 | 63 | 52 | 51 | 52 | 49 | 50 | 47 | **60** |
| Arbuckle-4 | 2007 | 18 | 21 | 18 | 28 | 21 | 21 | 22 | 18 | 22 | 24 | 23 | 23 | **22** |
| Arbuckle-3 | 2007 | 42 | 36 | 39 | 51 | 51 | 53 | 53 | 56 | 57 | 58 | 57 | 53 | **51** |
| Biggs | 2007 | 71 | 56 | 56 | 65 | 57 | 56 | 73 | 67 | 64 | 57 | 60 | 57 | **62** |
| Treatment mean* | | **52** | **48** | **49** | **57** | **52** | **51** | **53** | **51** | **53** | **51** | **54** | **51** | **52** |

*Does not include 2005 data

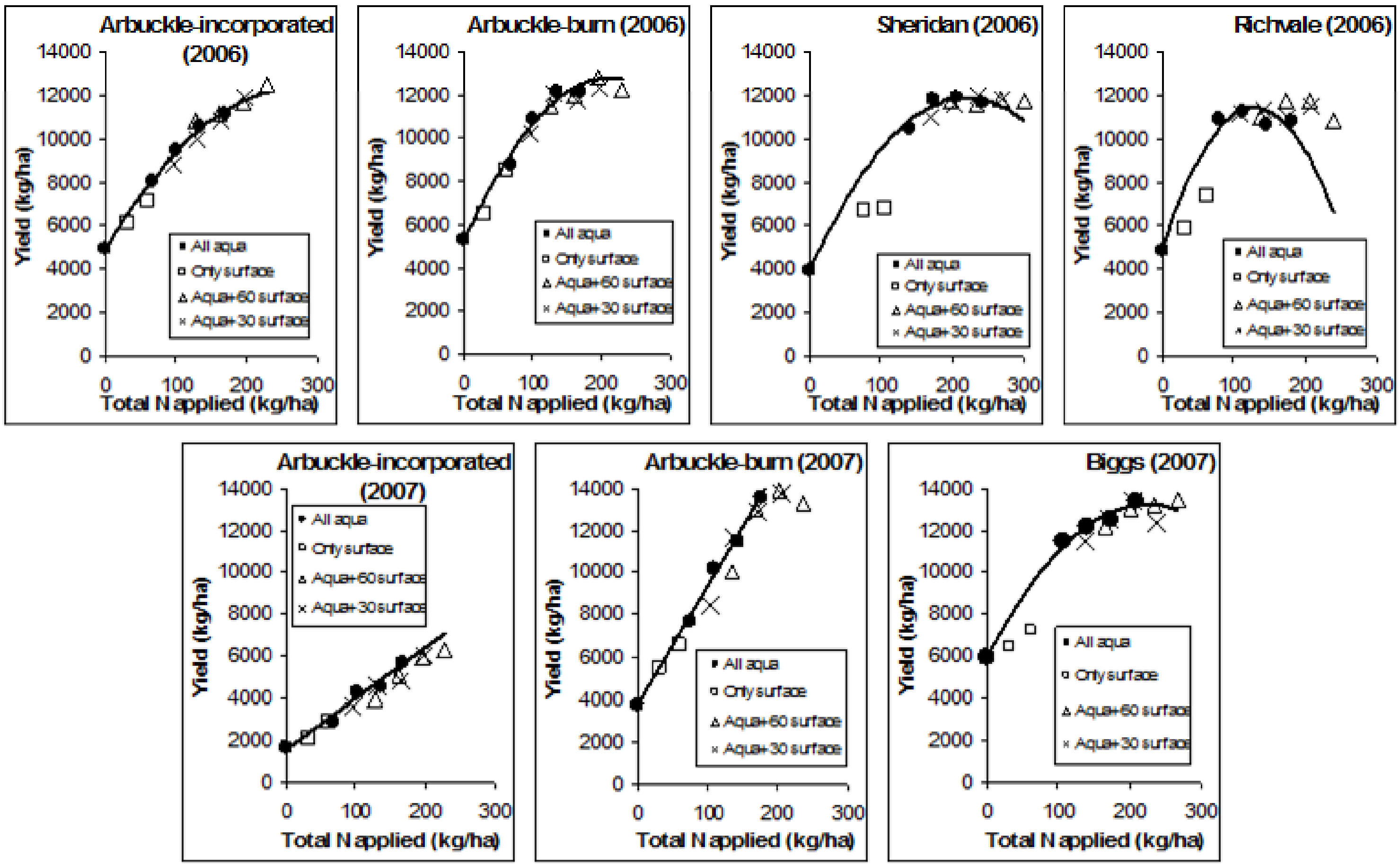


Figure 1. Grain yield response to deep (aqua) and surface applied N for all 2006 and 2007 experimental sites. The regression line fits the “all aqua” data points.

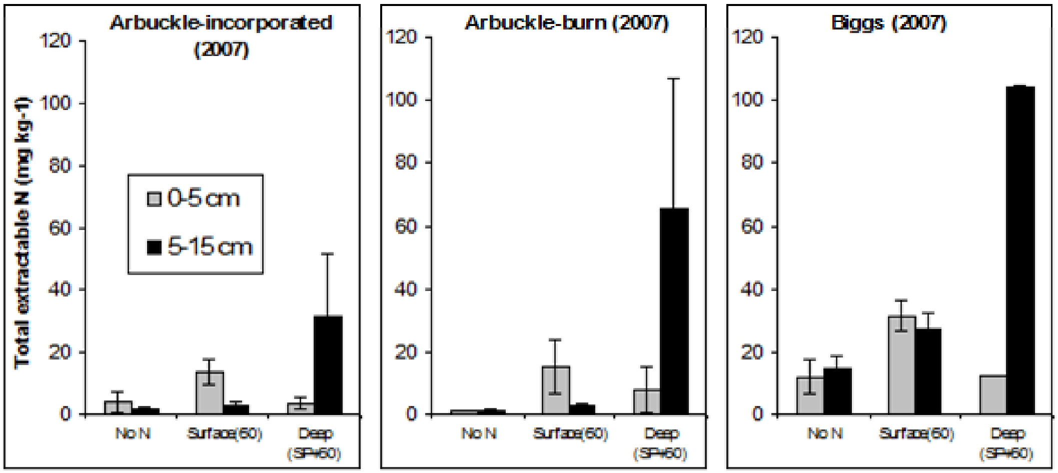


Figure 2. Total extractable N in the 0-5 cm and 5-15 cm soil layers in the control (0N), where only 60 kg N was applied to the surface (surface (60)), and where only aqua-N was injected to a depth of 10 cm at the standard aqua rate plus 60 kg N/ha (SP+60). Soil samples were taken approximately 2 weeks after sowing. Error bars represent the standard deviation of the three replications.

**P fertility management (2006 and 2007)**

1. Olsen-P soil extractable values ranged from 2 to 32 mg P/g soil. For this test the critical value is 6 mg P/g soil.
2. Leaf P concentration ranged from 0.12 to over 0.40 % (Figure 3). Of the five sites that had leaf P concentrations of 0.15% or less, all of them showed visual signs of early season P deficiency, however, yields were only significantly different at one of those sites. This value of 0.15% is generally in line with other reports from the literature, which suggests that leaf P concentrations of less than 0.1 to 0.14% indicate a critical deficiency.
3. Early season leaf tissue analysis showed that the addition of P fertilizer significantly increased leaf P concentration if the Olsen P value was less than 15 mg/g (Figure 6).
4. At only five sites was there a significant (P = 0.1) response to P fertilizer (Figure 4 and 5). At three of the 5 sites the Olsen P value was less than 6 mg/kg, however at the other two sites it was greater than 6 mg/kg.
5. These data suggest that the Olsen P test is not a useful test for rice growers in California. While values less than 6 mg/kg do suggest a deficiency, there are still positive responses to P when the value is well above 6 mg/kg.

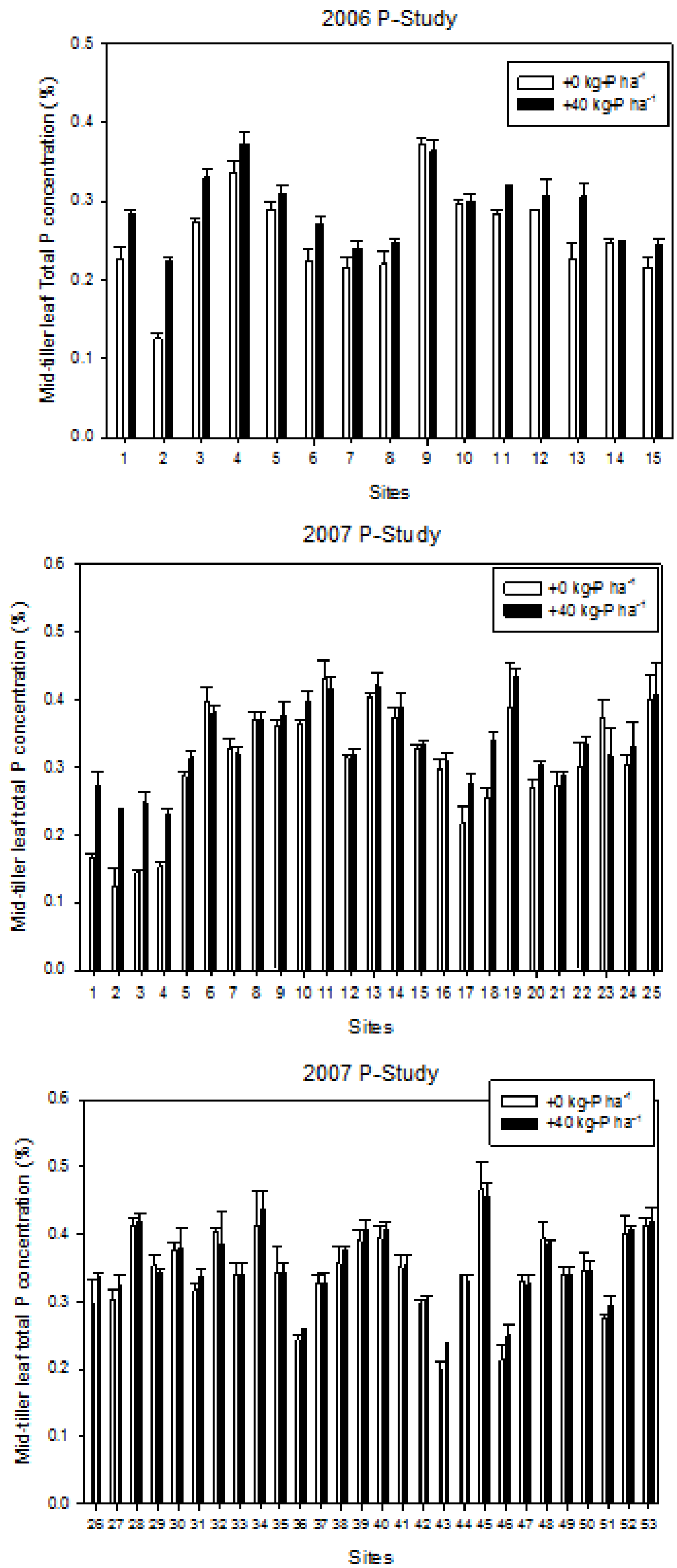


Figure 3. 2006 and 2007 mid-season (35 DAS) leaf P concentrations.

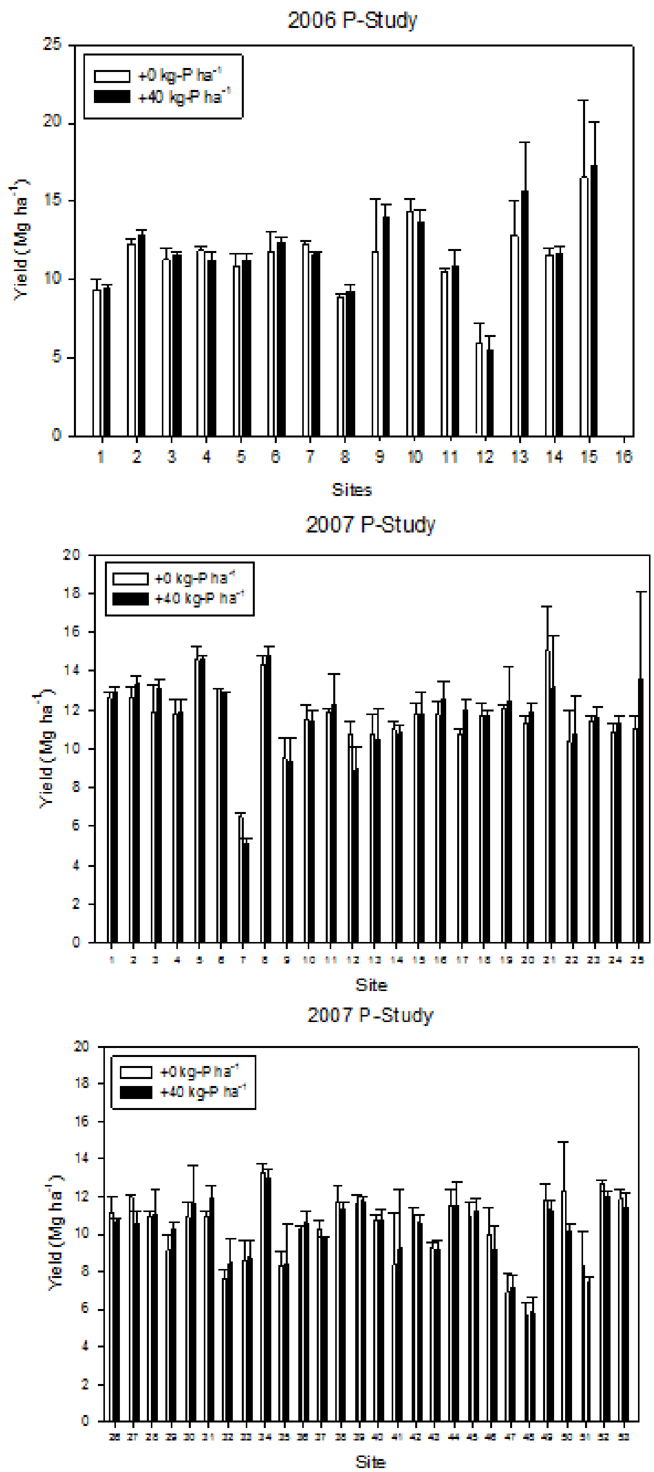


Figure 4. 2006 and 2007 rice yield responses to 0 and 40 kg P/ha.

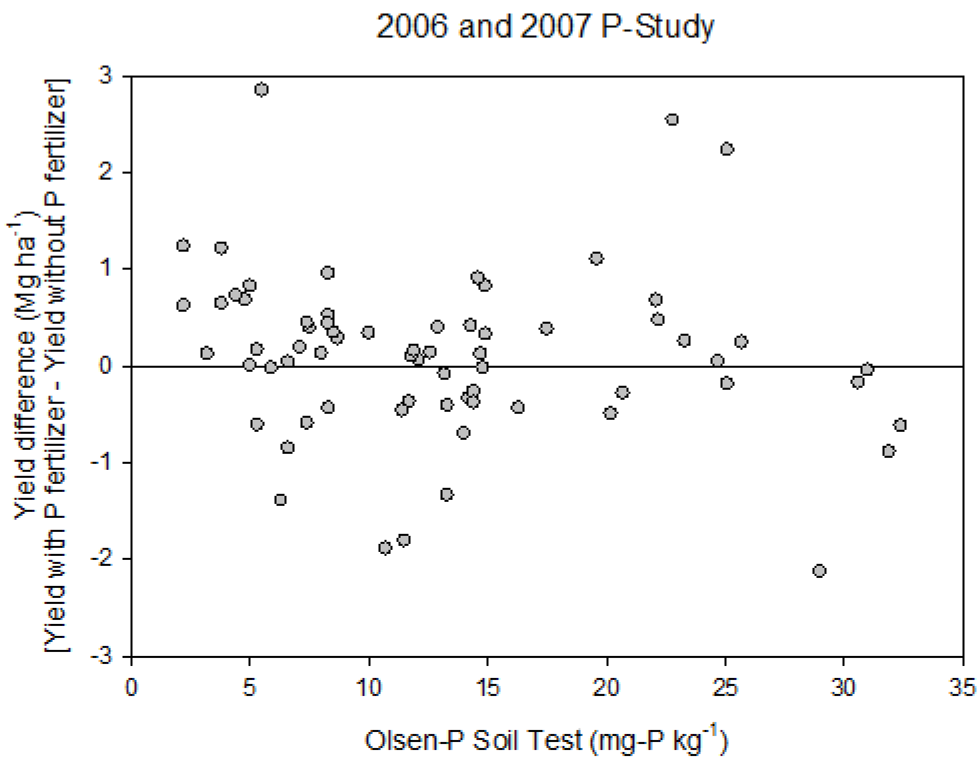


Figure 5. Yield response to P fertilizer as a function of Olsen P. The vertical line represents the critical value.

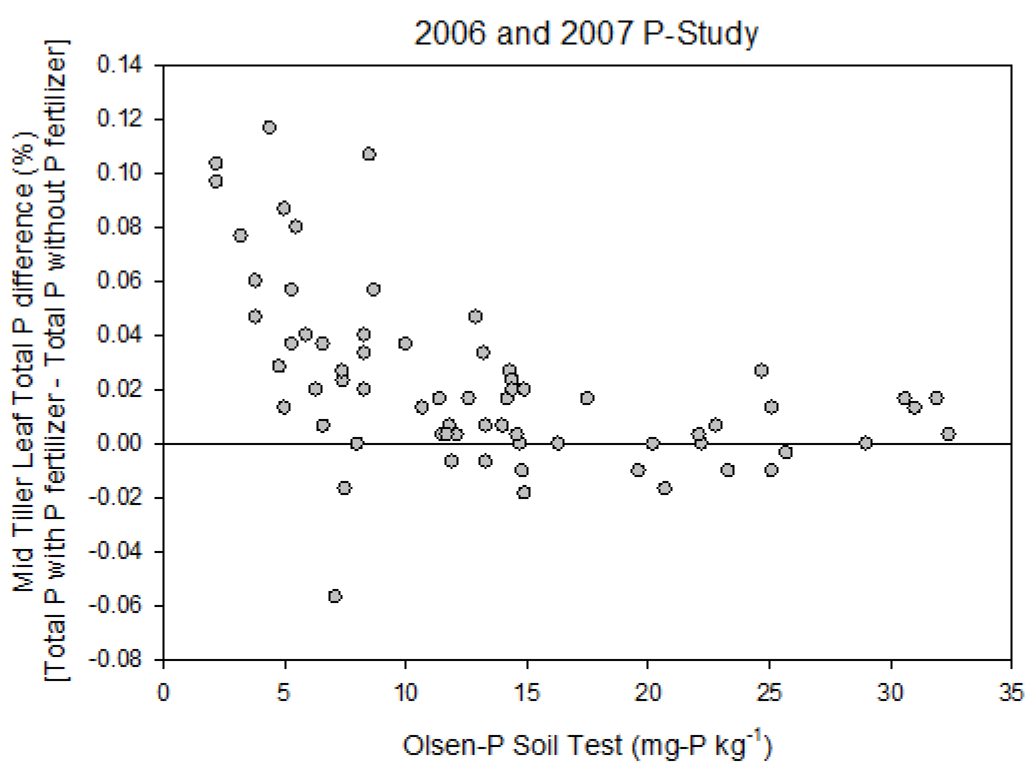


Figure 6. The change in mid-season leaf P concentration as a function of Olsen P.

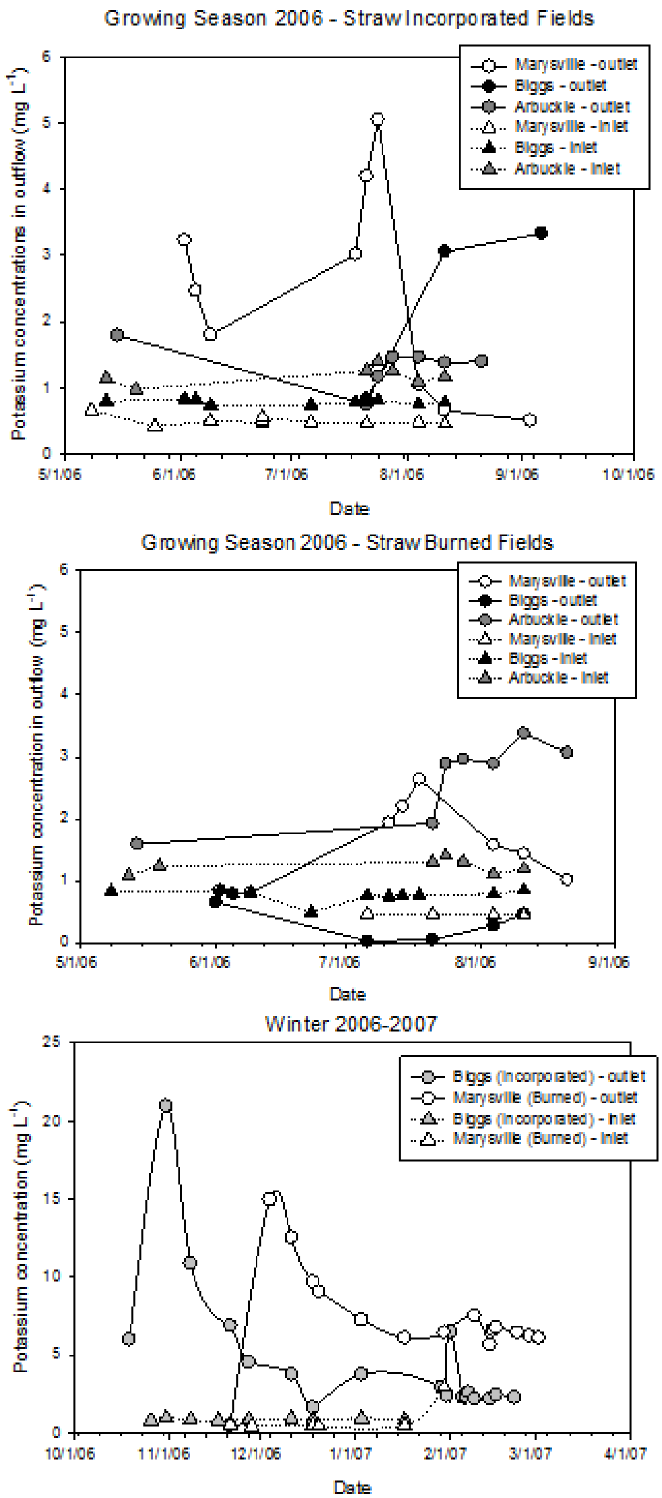


Figure 7. Potassium concentrations in inlet and outlet irrigation water for fields with varying straw management during both the growing season and the winter flood period.

**Potassium management**

The K concentrations in rice fields were monitored throughout the 2006 and 2007 growing seasons (2007 data not yet available) and during the winter of 2006/07.

1. K concentrations in the outlet waters were higher than the inlet water, with the exception of one field (Biggs-straw burned) (Figure 7). This indicates that irrigation water is removing K from the field.
2. During the winter flood period, the concentration of K in the outlet water can be very high (up to 20 X higher than the inlet) suggesting the potential for high K losses. The K concentrations in the field outlets are usually high at the beginning of the winter flood period then decline with time, although they remain consistently higher than the inlet waters.
3. While these data show the “potential” for loss, actual losses of K need to be determined based on load estimates. This requires knowing how much water entered and left the field.

**Economic Analysis**

From an economic standpoint, the results from the N fertility research indicate that growers could save money by applying all of their preplant fertilizer as aqua-N instead of splitting it between aqua-N and some starter N source. Aqua-N is about $0.30/lb cheaper than ammonium sulfate. In California 95% of growers apply starter N, applying on average 30 lb N/ac as starter fertilizer (http://www.plantsciences.ucdavis.edu/uccerice/NEWS/FertilityMgtSurvey2003.pdf). If a grower were to apply all of this N as aqua-N, the savings in terms of material costs would be $9.00/ac. Additionally, there are potential cost savings because the grower cold eliminate one pass across the field (either by air or tractor) to apply the starter N fertilizer.

While we have found that in most cases, there was not a yield increase from P fertilization, neither the soil P test nor the mid-season leaf tissue test allowed for an accurate determination as to whether or not it was necessary. Improved soil tests would allow a grower to skip P fertilization when soil P levels are sufficient-thus saving fertilizer costs.

With respect to K, our data show that losses of K could be substantial during the winter if growers flood their fields and then allow water to continually pass through the fields (a practice common with growers whose fields are used for duck hunting). Since we were not able to estimate nutrient loads the amount of K lost could not accurately be determined. This is however an area that could be explored further in the future.

**CONCLUSIONS**

Three years of research have provided the rice industry and growers have highlighted opportunities for growers to save money on their fertilizer costs as well as time savings in that they are able to reduce an application. However, we have also highlighted some critical areas that deserve further attention. First, the soil P and plant tissue tests are not very useful in determining if there is a need for P fertilizer application. Second, with respect to soil K fertility, there is the potential for significant losses from the field system due to excess water leaving the field.

# Appendix

Table 1. Site descriptions for the P studies in 2006 and 2007.

| Site # | Site Name | Year | Crop Mgt.* | Straw Mgt.** | Winter Water Mgt.*** | Variety | Planting Date | Preplant N | Aqua-Ammonia Rate |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | kg ha$^{-1}$ |
| 1 | Richvale(1)-E | 2006 | Continuous | Burn | Flooded | M206 | 5/8/06 | Aqua | 135 |
| 2 | Richvale(1)-W | 2006 | Continuous | Incorporate | Flooded | M202 | 5/16/06 | Aqua | 135 |
| 3 | Arbuckle(1)-W | 2006 | Rotation | Burn | None | M206 | 5/12/06 | Aqua | 152 |
| 4 | Arbuckle(1)-E | 2006 | Rotation | Incorporate | None | M206 | 5/13/06 | Aqua | 152 |
| 5 | Richvale(1)-E | 2006 | Continuous | Incorporate | Flooded | M206 | 5/21/06 | Aqua | 120 |
| 6 | Richvale(1)-W | 2006 | Continuous | Incorporate | Flooded | M202 | 5/13/06 | Aqua | 120 |
| 7 | Live Oak(1)-N | 2006 | Continuous | Burn | None | M205 | 5/15/06 | Aqua | 146 |
| 8 | Live Oak(2)-S | 2006 | Continuous | Incorporate | Flooded | Calmoti | 5/15/06 | Aqua | 146 |
| 9 | Knights Landing(1) | 2006 | Rotation | Incorporate | None | M206 | 5/18/06 | none | 0 |
| 10 | Knights Landing(2) | 2006 | Rotation | Incorporate | None | M206 | 5/26/06 | none | 0 |
| 11 | RES-W | 2006 | Continuous | Incorporate | Flooded | M202 | 5/20/06 | Aqua | 112 |
| 12 | RES-E | 2006 | Continuous | Incorporate | Flooded | M201 | 5/24/06 | Aqua | 112 |
| 13 | Durham(1) | 2006 | Continuous | Incorporate | None | M401 | 5/13/06 | Aqua | 110 |
| 14 | Marysville(1) | 2006 | Continuous | Incorporate | None | M202 | 5/23/06 | none | 0 |
| 15 | Richvale(3) | 2006 | Continuous | Incorporate | Filled w/ rainfall | M206 | 6/2/06 | Aqua | 113 |
| 16 | Richvale(4)-Burn-N | 2007 | Continuous | Burn | None | M205 | 4/16/07 | Aqua | 135 |
| 17 | Richvale(4)-Burn-S | 2007 | Continuous | Burn | None | M205 | 4/16/07 | Aqua | 135 |
| 18 | Richvale(4)-Incorp-N | 2007 | Continuous | Incorporate | Flooded | M206 | 4/24/07 | Aqua | 135 |
| 19 | Richvale(4)-Incorp-S | 2007 | Continuous | Incorporate | Flooded | M206 | 4/24/07 | Aqua | 135 |
| 20 | Knights Landing(3)-S | 2007 | Rotation | Incorporate | None | M206 | 5/1/2007 | none | 0 |
| 21 | Knights Landing(4)-N | 2007 | Rotation | Incorporate | None | M206 | 5/15/07 | none | 0 |
| 22 | Meridian-N | 2007 | Continuous | Incorporate | Flooded | KRM2 | 4/27/07 | Aqua | 99 |
| 23 | Meridian-S | 2007 | Continuous | Incorporate | Flooded | Kokoho | 4/25/07 | Aqua | 99 |
| 24 | Live Oak(3) | 2007 | Continuous | Burn | None | Cal Mochi 101 | 5/18/07 | Aqua | 146 |
| 25 | Live Oak(4)-N | 2007 | Continuous | Burn | None | M205 | 5/15/07 | Aqua | 146 |
| 26 | Live Oak(4)-S | 2007 | Continuous | Incorporate | None | M205 | 5/15/07 | Aqua | 146 |
| 27 | Live Oak(5) | 2007 | Continuous | Chopped | Flooded | M205 | 5/14/07 | Aqua | 152 |
| 28 | Colusa(1)-N | 2007 | Continuous | Incorporate | Filled w/ rainfall | L206 | 5/13/07 | Aqua | 169 |
| 29 | Colusa(1)-S | 2007 | Continuous | Incorporate | Filled w/ rainfall | L206 | 5/13/07 | Aqua | 169 |

| Site # | Site Name | Year | Crop Mgt.* | Straw Mgt.** | Winter Water Mgt.*** | Variety | Planting Date | Preplant N | Aqua-Ammonia Rate |
|---|---|---|---|---|---|---|---|---|---|
| 30 | Willows(1)-N | 2007 | Continuous | Burn | None | M205 | 4/30/07 | Aqua | 113 |
| 31 | Willows(1)-S | 2007 | Continuous | Incorporate | Flooded | M205 | 4/30/07 | Aqua | 113 |
| 32 | Verona(1)-W | 2007 | Continuous | Burn | None | M206 | 5/1/07 | Aqua | 135 |
| 33 | Verona(1)-E | 2007 | Continuous | Incorporate | Flooded | M206 | 5/1/07 | Aqua | 135 |
| 34 | Richvale(5)-W | 2007 | Continuous | Incorporate | Flooded | M206 | 5/6/07 | Aqua | 113 |
| 35 | Richvale(5)-E | 2007 | Continuous | Incorporate | Flooded | M206 | 5/12/07 | Aqua | 122 |
| 36 | Arbuckle-N | 2007 | Rotation | Incorporate | None | M202 | 4/27/07 | Aqua | 152 |
| 37 | Arbuckle-S | 2007 | Rotation | Burn | None | M206 | 4/28/07 | Aqua | 108 |
| 38 | Durham(2)-W | 2007 | Continuous | Incorporate | None | M206 | 5/6/07 | Aqua | 113 |
| 39 | Gridley(1)-N | 2007 | Continuous | Chopped | Flooded | M206 | 5/9/07 | Aqua | 146 |
| 40 | Gridley(1)-S | 2007 | Continuous | Burn | None | M206 | 5/14/07 | Aqua | 124 |
| 41 | Willows(2)-E | 2007 | Continuous | Burn | None | M205 | 5/4/07 | Aqua | 158 |
| 42 | Willows(2)-W | 2007 | Continuous | Incorporate | Flooded | M205 | 5/4/07 | Aqua | 152 |
| 43 | Delevan(1)-S | 2007 | Continuous | Bailed | None | M205 | 5/8/07 | Aqua | 125 |
| 44 | Delevan(2)-W | 2007 | Continuous | Burn | None | M205 | 5/14/07 | none | 0 |
| 45 | Delevan(2)-E | 2007 | Continuous | Burn | None | M205 | 5/14/07 | Aqua | 125 |
| 46 | Princeton-N | 2007 | Continuous | None | Flooded | M206 | 5/6/07 | Aqua | 124 |
| 47 | Princeton-S | 2007 | Continuous | None | Flooded | M206 | 4/26/07 | urea | 124 |
| 48 | Colusa Bypass(1) | 2007 | Continuous | None | Flooded | M206 | 6/12/07 | Aqua | 27 |
| 49 | Bayliss | 2007 | Continuous | Bailed | None | M205 | 5/1/07 | Aqua | 152 |
| 50 | Richvale(7) | 2007 | Continuous | Incorporate | Filled w/ rainfall | Arborio | 5/27/07 | Aqua | 113 |
| 51 | Pennington | 2007 | Continuous | Burn | Filled w/ rainfall | M206 | 5/15/07 | Aqua | 135 |
| 52 | Davis | 2007 | Continuous | None | None | Akita Kamacich | 5/6/07 | Urea | 78 |
| 53 | Verona(2)-S | 2007 | Continuous | Chopped | Flooded | M202 | 5/12/07 | Aqua | 113 |
| 54 | Verona(2)-N | 2007 | Continuous | Chopped | Flooded | M206 | 5/20/07 | Aqua | 113 |
| 55 | Colusa(2)-N | 2007 | Continuous | Incorporate | None | M202 | 5/15/07 | Aqua | 146 |
| 56 | Colusa(2)-S | 2007 | Continuous | Incorporate | Flooded | M206 | 5/14/07 | Aqua | 146 |
| 57 | Colusa(3) | 2007 | Continuous | Chopped | Flooded | M206 | 5/26/07 | Aqua | 146 |
| 58 | Richvale(8) | 2007 | Continuous | Incorporate | Flooded | M402 | 5/11/07 | Aqua | 96 |
| 59 | Gridley(2)-E | 2007 | Continuous | Burn | None | M206 | 5/16/07 | Aqua | 141 |
| 60 | Gridley(2)-W | 2007 | Continuous | Chopped | Flooded | M206 | 5/16/07 | Aqua | 141 |
| 61 | Biggs | 2007 | Continuous | Burn | Flooded | M205 | 5/23/07 | Aqua | 146 |
| 62 | Marysville(2)-N | 2007 | Continuous | Incorporate | Flooded | Koshikihari | 5/26/07 | none | 0 |
| 63 | Marysville(2)-S | 2007 | Continuous | Burn | Flooded | Koshikihari | 5/22/07 | none | 0 |

| Site # | Site Name | Year | Crop Mgt.* | Straw Mgt.** | Winter Water Mgt.*** | Variety | Planting Date | Preplant N | Aqua-Ammonia Rate |
|---|---|---|---|---|---|---|---|---|---|
| 64 | Colusa Bypass(2) | 2007 | Continuous | None | Flooded | M206 | 5/22/07 | Aqua | 113 |
| 65 | Colusa Bypass(3) | 2007 | Continuous | None | Filled w/ rainfall | M202 | 5/16/07 | Aqua | 113 |
| 66 | Kirkville | 2007 | Continuous | Incorporate | None | M202 | 6/2/07 | Aqua | 135 |
| 67 | Pleasant Grove-N | 2007 | Continuous | Incorporate | Flooded | M206 | 5/22/07 | Riceplex | 115 |
| 68 | Pleasant Grove-S | 2007 | Continuous | Incorporate | None | M206 | 5/23/07 | Riceplex | 115 |

* Crop management indicates if rice was grown continuously (greater then five consecutive years) or in rotation with other grain crops.
** Straw management indicates if the straw was incorporated into the soil after harvest, burned, bailed, or chopped, but not incorporated.
*** Winter water management indicates if the field was intentionally flooded, flooded with rainfall, or was not allowed to flood.

**Table 2. 2005 results from the NPK fertility study**

**Arbuckle**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | | | Yield (kg ha $^{-1}$) |
|---|---|---|---|---|---|---|---|
| # | Basal N | Starter | T1 (22 DAS) | T2 (30 DAS) | T3 (37 DAS) | Harvest | Harvest |
| 1 | 0 | - PK | 30 b | 95 c | 212 d | 6494 d | 3256 d |
| 2 | Yes | - - - | 30 b | 112 bc | 306 c | 14306 b | 7739 b |
| 3 | Yes | N - - | | | 453 a | 16885 a | 9304 a |
| 4 | 0 | NPK | 36 a | 156 a | 379 b | 9085 c | 4562 c |
| 5 | Yes | NPK | 35 a | 172 a | 442 a | 17009 a | 9356 a |
| 6 | Yes | - PK | 33 ab | 124 b | 368 bc | 14196 b | 7643 b |
| 7 | Yes | N- K | | | 412 ab | 16098 a | 8738 a |
| 8 | Yes | NP - | | | 456 a | 17085 a | 9374 a |
| ANOVA (P) | | | 0.0508 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Sheridan**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | | | Yield (kg ha $^{-1}$) |
|---|---|---|---|---|---|---|---|
| # | Basal N | Starter | T1 (26 DAS) | T2 (31 DAS) | T3 (38 DAS) | Harvest | Harvest |
| 1 | 0 | - PK | 190 c | 418 c | 546 f | 8145 c | 3074 b |
| 2 | Yes | - - - | 212 bc | 499 b | 703 de | 18970 ab | 9855 a |
| 3 | Yes | N - - | | | 901 ab | 19281 ab | 9637 a |
| 4 | 0 | NPK | 249 a | 530 ab | 675 e | 9374 c | 4030 b |
| 5 | Yes | NPK | 249 a | 580 a | 959 a | 19506 a | 9638 a |
| 6 | Yes | - PK | 226 a | 475 b | 709 cde | 17051 b | 8839 a |
| 7 | Yes | N- K | | | 819 bc | 18549 ab | 9487 a |
| 8 | Yes | NP - | | | 759 bcd | 19072 ab | 9603 a |
| ANOVA (P) | | | 0.0037 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |

**Princeton**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | | | Yield (kg ha $^{-1}$) |
|---|---|---|---|---|---|---|---|
| # | Basal N | Starter | T1 (22 DAS) | T2 (29 DAS) | T3 (35 DAS) | Harvest | Harvest |
| 1 | 0 | - PK | 119 c | 233 d | 578 e | 8174 c | 3775 b |
| 2 | Yes | - - - | 144 b | 315 c | 879 cd | 20443 a | 10243 a |
| 3 | Yes | N - - | | | 1036 ab | 20251 a | 10167 a |
| 4 | 0 | NPK | 190 a | 382 b | 841 d | 10132 b | 4553 b |
| 5 | Yes | NPK | 207 a | 460 a | 1163 a | 21064 a | 10144 a |
| 6 | Yes | - PK | 164 b | 353 bc | 1003 bc | 20694 a | 10221 a |
| 7 | Yes | N- K | | | 1006 bc | 20962 a | 10096 a |
| 8 | Yes | NP - | | | 1116 ab | 21494 a | 10476 a |
| ANOVA (P) | | | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Gridley**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | | | Yield (kg ha $^{-1}$) |
|---|---|---|---|---|---|---|---|
| # | Basal N | Starter | T1 (21 DAS) | T2 (27 DAS) | T3 (35 DAS) | Harvest | Harvest |
| 1 | 0 | - PK | 136 b | 306 c | 726 d | 8945 d | 4132 c |
| 2 | Yes | - - - | 145 b | 287 c | 681 d | 15106 c | 8636 b |
| 3 | Yes | N - - | | | 741 d | 17183 a | 10033 a |
| 4 | 0 | NPK | 159 ab | 368 b | 960 c | 10106 d | 4720 c |
| 5 | Yes | NPK | 187 a | 412 a | 1312 ab | 16021 abc | 8676 b |
| 6 | Yes | - PK | 182 a | 410 a | 1249 b | 15894 bc | 8511 b |
| 7 | Yes | N- K | | | 760 d | 17081 ab | 9939 a |
| 8 | Yes | NP - | | | 1424 a | 16451 ab | 9029 b |
| ANOVA (P) | | | 0.0071 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Richvale**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | | | Yield (kg ha $^{-1}$) |
|---|---|---|---|---|---|---|---|
| # | Basal N | Starter | T1 (20 DAS) | T2 (26 DAS) | T3 (33 DAS) | Harvest | Harvest |
| 1 | 0 | - PK | 69 c | 215 c | 578 e | 13111 d | 6940 d |
| 2 | Yes | - - - | 75 bc | 293 b | 915 cd | 18472 b | 10801 b |
| 3 | Yes | N - - | | | 988 bcd | 19821 ab | 11236 ab |
| 4 | 0 | NPK | 82 ab | 306 b | 871 d | 15451 c | 8304 c |
| 5 | Yes | NPK | 87 a | 345 a | 1148 ab | 20749 a | 12361 a |
| 6 | Yes | - PK | 76 bc | 289 b | 916 cd | 19796 ab | 10924 b |
| 7 | Yes | N- K | | | 1098 abc | 21413 a | 11642 ab |
| 8 | Yes | NP - | | | 1206 a | 20362 ab | 11619 ab |
| ANOVA (P) | | | 0.0093 | 0.0000 | 0.0001 | 0.0000 | 0.0000 |

Table 3 (2006). Above ground biomass for each treatment at three sampling dates (between 2 and 5 weeks after sowing). SP=standard aqua N rate; DAS=days after sowing

**Arbuckle-Burn**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| # | Basal Aqua N | Starter Fertilizer | T1 (20 DAS) | T2 (27 DAS) | T3 (33 DAS) |
| 1 | 0 | 0 | 119 c | 356 c | 701 |
| 2 | 0 | 30 | 159 ab | 581 b | 1193 |
| 3 | 0 | 60 | | | 1581 |
| 4 | SP-30 | 0 | | | 1230 |
| 5 | SP-30 | 30 | | | 1554 |
| 6 | SP-30 | 60 | | | 1552 |
| 7 | SP | 0 | 135 bc | 602 b | 1519 |
| 8 | SP | 30 | 180 a | 714 a | 1617 |
| 9 | SP | 60 | | | 1890 |
| 10 | SP+30 | 0 | 154 ab | 627 ab | 1302 |
| 11 | SP+30 | 30 | | | 1588 |
| 12 | SP+30 | 60 | | | 1813 |
| 13 | SP+60 | 0 | 135 bc | 649 ab | 1551 |
| 14 | SP+60 | 30 | | | 1885 |
| 15 | SP+60 | 60 | | | 1897 |
| **ANOVA (P)** | | **T1 and T2** | **0.0068** | **0.0002** | |
| | | **Aqua N** | | | **0.0043** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.0507** |

**Arbuckle-Incorporate**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| # | Basal Aqua N | Starter Fertilizer | T1 (19 DAS) | T2 (26 DAS) | T3 (33 DAS) |
| 1 | 0 | 0 | 130 c | 431 c | 790 |
| 2 | 0 | 30 | 157 a | 613 b | 1147 |
| 3 | 0 | 60 | | | 1670 |
| 4 | SP-30 | 0 | | | 1513 |
| 5 | SP-30 | 30 | | | 1672 |
| 6 | SP-30 | 60 | | | 2061 |
| 7 | SP | 0 | 139 bc | 572 b | 1293 |
| 8 | SP | 30 | 155 ab | 613 b | 1567 |
| 9 | SP | 60 | | | 1745 |
| 10 | SP+30 | 0 | 157 a | 795 a | 2074 |
| 11 | SP+30 | 30 | | | 2124 |
| 12 | SP+30 | 60 | | | 2324 |
| 13 | SP+60 | 0 | 152 ab | 748 a | 2160 |
| 14 | SP+60 | 30 | | | 2450 |
| 15 | SP+60 | 60 | | | 2262 |
| **ANOVA (P)** | | **T1 and T2** | **0.0224** | **0.0000** | |
| | | **Aqua N** | | | **0.0000** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.0049** |

Sheridan

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| # | Basal Aqua N | Starter Fertilizer | T1 (14 DAS) | T2 (23 DAS) | T3 (35 DAS) |
| 1 | 0 | 0 | 46 | 367 | 1078 |
| 2 | 0 | 30 | 48 | 368 | 1259 |
| 3 | 0 | 60 | | | 1532 |
| 4 | SP-30 | 0 | | | 1561 |
| 5 | SP-30 | 30 | | | 1551 |
| 6 | SP-30 | 60 | | | 1654 |
| 7 | SP | 0 | 45 | 351 | 1444 |
| 8 | SP | 30 | 49 | 397 | 1660 |
| 9 | SP | 60 | | | 1742 |
| 10 | SP+30 | 0 | 47 | 369 | 1539 |
| 11 | SP+30 | 30 | | | 1656 |
| 12 | SP+30 | 60 | | | 1746 |
| 13 | SP+60 | 0 | 45 | 372 | 1588 |
| 14 | SP+60 | 30 | | | 1786 |
| 15 | SP+60 | 60 | | | 1718 |
| **ANOVA (P)** | | **T1 and T2** | **0.3873** | **0.4165** | |
| | | **Aqua N** | | | **0.0319** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.0740** |

Richvale

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| # | Basal Aqua N | Starter Fertilizer | T1 (17 DAS) | T2 (27 DAS) | T3 (34 DAS) |
| 1 | 0 | 0 | 114 bc | 693 b | 1883 |
| 2 | 0 | 30 | 137 a | 981 a | 2553 |
| 3 | 0 | 60 | | | 3476 |
| 4 | SP-30 | 0 | | | 2983 |
| 5 | SP-30 | 30 | | | 3093 |
| 6 | SP-30 | 60 | | | 2905 |
| 7 | SP | 0 | 110 c | 938 a | 3369 |
| 8 | SP | 30 | 128 ab | 1089 a | 3259 |
| 9 | SP | 60 | | | 3379 |
| 10 | SP+30 | 0 | 133 a | 1022 a | 3037 |
| 11 | SP+30 | 30 | | | 3492 |
| 12 | SP+30 | 60 | | | 3826 |
| 13 | SP+60 | 0 | 131 a | 961 a | 3608 |
| 14 | SP+60 | 30 | | | 3510 |
| 15 | SP+60 | 60 | | | 3946 |
| **ANOVA (P)** | | **T1 and T2** | **0.0102** | **0.0108** | |
| | | **Aqua N** | | | **0.0153** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.0004** |

Table 4 (2007). Above ground biomass for each treatment at three sampling dates (between 2 and 5 weeks after sowing). SP=standard aqua N rate; DAS=days after sowing

**Arbuckle-Burn**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (13 DAS)** | **T2 (20 DAS)** | **T3 (39 DAS)** |
| 1 | 0 | 0 | 20.42 | 44.96 d | 619.87 |
| 2 | 0 | 30 | 26.37 | 71.23 ab | 1227.60 |
| 3 | 0 | 60 | | | 1433.39 |
| 4 | SP-30 | 0 | | | 1303.51 |
| 5 | SP-30 | 30 | | | 1470.02 |
| 6 | SP-30 | 60 | | | 1953.47 |
| 7 | SP | 0 | 21.09 | 62.79 c | 1508.40 |
| 8 | SP | 30 | 23.40 | 74.76 a | 1768.78 |
| 9 | SP | 60 | | | 2083.36 |
| 10 | SP+30 | 0 | 21.13 | 63.34 c | 1651.84 |
| 11 | SP+30 | 30 | | | 1979.43 |
| 12 | SP+30 | 60 | | | 2061.82 |
| 13 | SP+60 | 0 | 23.36 | 64.98 bc | 1777.27 |
| 14 | SP+60 | 30 | | | 2022.57 |
| 15 | SP+60 | 60 | | | 2239.64 |
| **ANOVA (P)** | | **T1 and T2** | **0.0686** | **0.0001** | |
| | | **Aqua N** | | | **0.0009** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.6177** |

**Arbuckle-Incorporate**

| Treatment | | | Above ground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (14 DAS)** | **T2 (221 DAS)** | **T3 (38 DAS)** |
| 1 | 0 | 0 | 28.45 | 55.62 c | 270.58 |
| 2 | 0 | 30 | 34.53 | 86.44 ab | 595.05 |
| 3 | 0 | 60 | | | 861.21 |
| 4 | SP-30 | 0 | | | 883.33 |
| 5 | SP-30 | 30 | | | 967.53 |
| 6 | SP-30 | 60 | | | 1372.18 |
| 7 | SP | 0 | 24.94 | 74.08 b | 719.17 |
| 8 | SP | 30 | 32.44 | 92.77 a | 897.00 |
| 9 | SP | 60 | | | 1120.58 |
| 10 | SP+30 | 0 | 33.50 | 83.93 ab | 1024.71 |
| 11 | SP+30 | 30 | | | 1160.66 |
| 12 | SP+30 | 60 | | | 1345.95 |
| 13 | SP+60 | 0 | 31.02 | 92.30 a | 1234.27 |
| 14 | SP+60 | 30 | | | 1099.88 |
| 15 | SP+60 | 60 | | | 1401.49 |
| **ANOVA (P)** | | **T1 and T2** | **0.0987** | **0.0006** | |
| | | **Aqua N** | | | **0.0015** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.4813** |

**Richvale**

| # | Basal Aqua N | Starter Fertilizer | T1 (14 DAS) | T2 (21 DAS) | T3 (34 DAS) |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 25.09 | 72.41 c | 529.75 |
| 2 | 0 | 30 | 28.16 | 94.02 ab | 851.91 |
| 3 | 0 | 60 | | | 1088.01 |
| 4 | SP-30 | 0 | | | 874.00 |
| 5 | SP-30 | 30 | | | 1198.30 |
| 6 | SP-30 | 60 | | | 1306.19 |
| 7 | SP | 0 | 24.89 | 87.22 bc | 996.93 |
| 8 | SP | 30 | 28.44 | 106.07 a | 1179.42 |
| 9 | SP | 60 | | | 1406.51 |
| 10 | SP+30 | 0 | 26.18 | 106.92 a | 1052.01 |
| 11 | SP+30 | 30 | | | 1245.84 |
| 12 | SP+30 | 60 | 24.75 | 98.87 ab | 1369.19 |
| 13 | SP+60 | 0 | | | 1081.44 |
| 14 | SP+60 | 30 | | | 1130.41 |
| 15 | SP+60 | 60 | | | 1354.06 |
| **ANOVA (P)** | | **T1 and T2** | **0.1604** | **0.0113** | |
| | | **Aqua N** | | | **0.0213** |
| | | **Starter N** | | | **0.0000** |
| | | **Aqua X Starter** | | | **0.4794** |