# ANNUAL REPORT
# COMPREHENSIVE RESEARCH ON RICE
January 1, 2007 - December 31, 2007

**PROJECT TITLE:** Improving N use efficiency and quantifying changes in N dynamics in rice systems with varying early season water management practices.

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## OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

**Overarching Project Goal**:

The focus of the RM-4 project is to evaluate the impact of grower management practices on nutrient cycling, and to work in association with cooperative extension to develop improved fertility management guidelines for rice growers.

**2007 Project Goal:**

Develop N fertilizer guidelines for California rice growers practicing alternative early season water management strategies.

To meet this goal, two objectives were addressed:

1. To quantify N losses in rice fields as affected by early season water management. In addition, to identify critical periods in the flood-drain/dry-reflood cycle when N losses are the greatest.

2. 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.

In order to meet objective 1, experiments were conducted around the Sacramento Valley region. A controlled study to determine N losses due to early drainage for herbicide applications was conducted in two fields near Gridley. In order to better extrapolate these results to a wider area, soil N dynamics during the early season drain and reflood period was measured in 22 fields around the Sacramento Valley. Finally, we conducted research in the "systems" research site at the RES to develop improved nutrient management strategies for these alternative systems.

## Concise General Summary of 2007 Results

- Changes in early season water management (usually related to weed control) are currently the greatest challenge for nutrient (particularly N) management in California rice systems.
    - On average across 24 fields, nitrate-N accumulates at a rate of about 2 kg/ha/day during the course of the drain period.
    - By the end of the drain period, on average a total of 20 kg NO3-N had accumulated. At some site as much as 64 kg nitrate-N / ha had accumulated.
    - This NO3-N disappeared by about 7 days after reflooding. While a portion of the N was probably taken up by the crop much of it was probably lost via denitrification.
    - Surface and deep placed N was susceptible to N losses via nitrification and denitrification pathways.
    - As a result of the above mentioned factors, N use efficiency was lower in the drained fields than in the continuously flooded fields.
    - Extended drain periods can also result in drought stress

  - In three of the four controlled field studies, draining the fields resulted in significantly lower yields compared to the continuously flooded fields (on average by 550 kg/ha). This may be due to N losses, drought stress or both.

- Continued analysis of different rice establishment and alternative early season weed control methods indicates that the yield potential of these systems is similar. This result is consistent with the three previous years of data. However, the amount of N required to achieve the yield potential varies between systems. As with the Clincher program, early season water management affects soil N availability early in the season. In these systems, flash-flooding to recruit weeds (in stale seedbed systems) or to germinate rice seeds (drill seeded system) likely results in some denitirfication losses. The result is that the stale seedbed systems require up to 50 kg N/ha more than the conventionally managed systems
- Data from these studies indicate that N management practices need to be revised in these systems in order to achieve optimal yields, and efficient cost effective fertilizer N use.

**2007 Project Objective 1:** To quantify N losses in rice fields as affected by early season water management. In addition, to identify critical periods in the flood-drain/dry-reflood cycle when N losses are the greatest.

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, practices are changing and alternatives requiring an early season flooding-draining-reflooding event are growing in popularity.

This change in early season water management has direct implications for N fertility management. Current N recommendations were developed for fields that are continuously flooded through the growing season. The impact that flooding-draining-reflooding events in the early season have on fertility dynamics is not well understood, but is of critical importance to if growers are to manage N efficiently. 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.

Research in 2007 was conducted both on-farm and at the RES alternative stand establishment study site. In 2006, preliminary on-farm results suggested that the potential for N loss may vary depending on winter straw management. In 2007 we again incorporated a straw management variable into our experimental design so that the data would be comparable to 2006. But because it is likely the potential for N loss may also depend on other factors such as soil type, we expanded the scope in 2007 to include both more detailed studies in grower fields as well as intensive sampling on a large number of fields around the valley during the flood-drain/dry-reflood period.

*On-farm studies*

As in 2006, in 2007 we conducted research in two side-by-side grower fields (1 with straw incorporated, the other with straw burned) to examine the effect of draining on soil N dynamics, crop N uptake, growth, and yield. We expanded the number of treatments in 2007 to quantify individual use-efficiencies of surface, subsurface, and top-dress applied N. Due to the potential for N loss when fields are drained early in the season, it is likely that more N will be required as a top-dress application after reflooding. Therefore, it was important for us to begin measuring the efficiency of an increased rate of top-dress N application following reflooding.

In each field there were 3 replicates of the following treatments:

1. undrained + surface tracer N (US),
2. undrained + subsurface tracer N (USS),
3. drained + surface tracer N (DS),
4. drained + subsurface tracer N (DSS), and
5. drained + double the standard farmer top-dress N rate as tracer N (DTD).

Regular soil and plant samples were taken for analysis during the drain-reflood period, and at harvest.

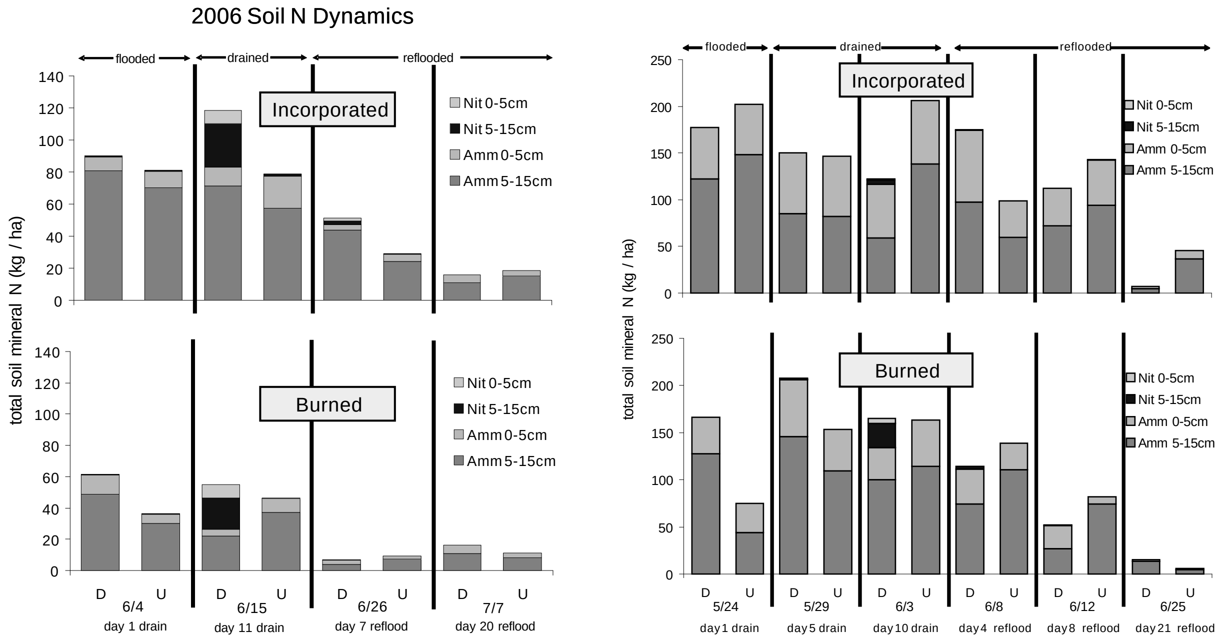

**Figure 1.** 2006 and 2007 soil mineral N dynamics of the Drained and Undrained treatments during the drain-reflood period in the incorporated and burned fields.

Nitrate accumulation amount to between 4 and 20 kg N / ha during the drain period in 2007 (Fig. 1). In 2006 the nitrate levels were somewhat higher, between 28-35 kg N / ha. Though this variability between years could have been due to the inherent differences between fields (Live Oak vs. Gridley), differences in water management likely played a larger role. In 2007 both the checks our experiment was positioned in were in the bottom of a grower's field. That area tended to dry out slowest during the drain (particularly the incorporated check, which was at the very bottom), and may never have reached the aerobic threshold required for rapid nitrification to occur. Unlike in 2006, in 2007 there were no consistent trends in ammonium dynamics during the drain or following reflooding, nor were there any noticeable differences between the burned or incorporated fields.

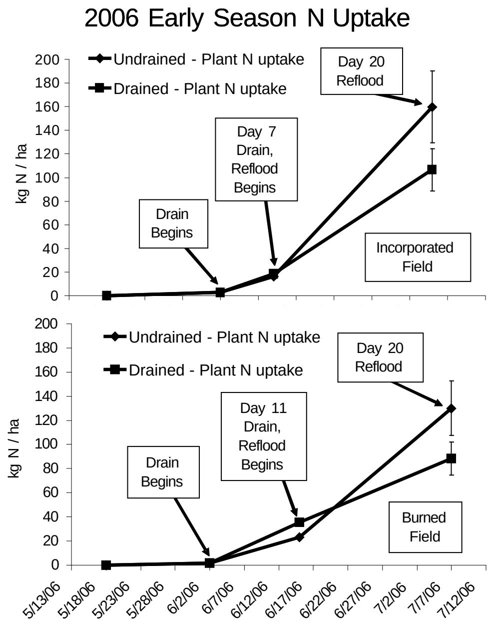

**Figure 2**. 2006 early season N uptake of the Drained and Undrained treatments, in both the incorporated and burned fields west of Live Oak.

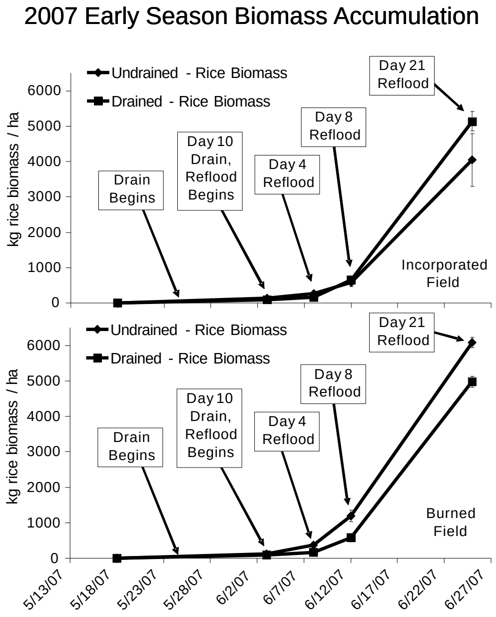

**Figure 3.** 2007 early season biomass accumulation of the Drained and Undrained treatments, in both the incorporated and burned fields west of Gridley.

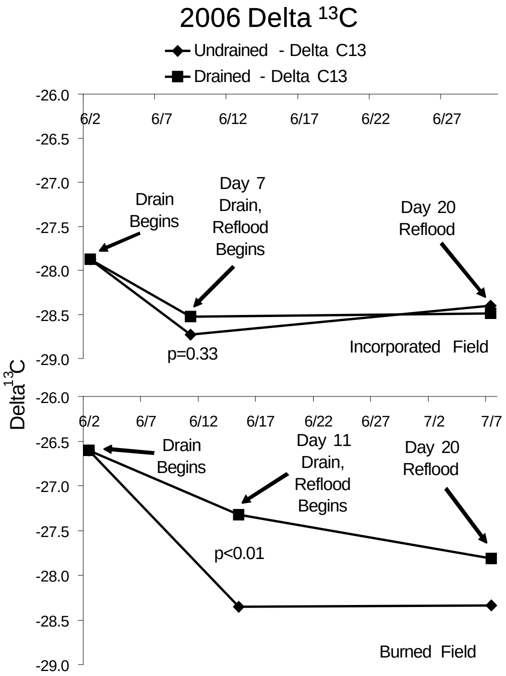

**Figure 4.** Delta 13C changes in the early season of 2006 in the Drained and Undrained treatments, in the burned and incorporated fields.

In 2006 the drain had a marked effect on N uptake and growth during the few weeks following reflooding, with the undrained treatment accumulating between 42-53 kg N / ha more than the drained treatment by 20 days following reflooding (Fig. 2). It is possible this reduced N uptake was due to a soil N deficiency from nitrate loss following reflooding. However, another possibility is that the drain period resulted in crop drought stress, stunting its early season growth. We analyzed the early season plant samples from 2006 using 13C isotopic methods to determine whether drought stress occurred in the drained treatment during the draining period. It has been well documented in the literature that the delta 13C value of a plant decreases as drought stress increases. Our 13C data indicate that photosynthetic capacity (and potentially N uptake) was compromised by drought stress during the drain, particularly in the burned field, where differences in Delta 13C values were highly significant just before the reflood (Fig. 4). The early season plant samples from 2007 are currently being analyzed for 13C as well to determine if drought stress occurred as well.

Though the early season plant N data from 2007 is still being analyzed, the biomass data show that early season growth was once again reduced in the drained treatment, with one notable exception not likely due to true treatment differences (Fig. 3). In the burned field the undrained treatment had higher biomass at every sampling point. In the incorporated field the undrained treatment had higher biomass at every sampling point until 8 days following reflooding, after which the drained treatment was higher. There is good reason to believe biomass in the drained treatment was higher after that point due to a methodological problem encountered in our experimental approach. During the drain period, the rings in the incorporated field had a substantial amount of straw floating on the surface. Since the undrained rings remained full of water throughout the drain, the rice plants were much taller than in the drained rings during that time. Before the Clincher was applied at the end of the drain period, water in the undrained rings was quickly siphoned out so weeds would be exposed to the Clincher consistently across both treatments and all rings. Unfortunately the taller rice plants in the undrained rings did not support themselves well with rapidly dropping water. In addition, the weight of wet straw settling on the rice plants as the rings were quickly drained compounded the problem. Upon quickly reflooding the undrained rings following the Clincher application, the exposed parts of many of the rice plants were lying flat on the water's surface. It is possible this experimental artifact impacted subsequent rice growth and yield in the undrained treatment in the incorporated field.

In an effort to quantify any differences in N-use efficiency of surface, subsurface, or top-dressing forms of N application between the drained and undrained treatments, we utilized tracer N in 2007 as the source of N fertilizer applied to the rings. In both the incorporated and burned fields the percent N fertilizer use efficiency of the surface and subsurface sources combined, was higher in the undrained than the drained treatment. In the incorporated field the percent of N fertilizer recovered in the rice crop (grain+straw) of the drained and undrained treatments at harvest was 39% and 45%, respectively. Though these differences were not statistically significant, in the burned field they were (p=0.003) where the drained and undrained treatments had efficiencies of 30% and 37%, respectively.

Differences in N fertilizer use efficiency of surface (i.e. starter), subsurface (i.e. aqua), and topdress applications were consistent within both treatments, in both fields. On average, fertilizer use efficiency of subsurface N was 12% higher than surface N (40% vs 28%), and 29% higher than an increased top-dress N rate (40% vs 11%).

**Table 1.** 2006-2007 yield (kg/ha, adjusted to 14% moisture) and total N uptake (kg/ha) of the Drained and Undrained treatments, in incorporated and burned fields.

| Year | Field Location | Straw Management | Treatment | Yield (kg/ha 14%) | p value | Total N Uptake (kg/ha) | p value |
|---|---|---|---|---|---|---|---|
| 2006 | Live Oak, CA | Burned | Drained | 11198 ± 159 | 0.067 | 138 ± 4 | 0.041 |
| | | | Undrained | 11973 ± 354 | | 158 ± 8 | |
| | | Incorporated | Drained | 11851 ± 45 | 0.549 | 139 ± 3 | 0.003 |
| | | | Undrained | 11964 ± 142 | | 154 ± 3 | |
| 2007 | Gridley, CA | Burned | Drained | 13106 ± 791 | 0.061 | 173 ± 4 | 0.042 |
| | | | Undrained | 13862 ± 786 | | 187 ± 3 | |
| | | Incorporated | Drained | 13973 ± 860 | 0.471 | 207 ± 9 | 0.314 |
| | | | Undrained | 13544 ± 579 | | 203 ± 7 | |

In 2006 yields and total N uptake were higher in the Undrained than in the Drained treatment, in both fields (only N uptake was statistically different) (Table 1). In 2007 the Undrained treatment had statistically higher yields and N uptake than the Drained treatment in the burned field. However in the incorporated field the opposite was true, though differences were not statistically significant.

To further extrapolate our results across a wider region and to quantify nitrification and nitrate loss rates, we identified 22 conventional fields with different soil types across the valley that were to receive an early season drain for an herbicide application. In addition, we identified 7 organic fields which would be subjected to an extended draining and drying period as a cultural weed control measure. On all these fields soil was sampled from 0-15cm on average every 3-4 days during the critical flood-drain/dry-reflood phase to monitor changes in soil N status.

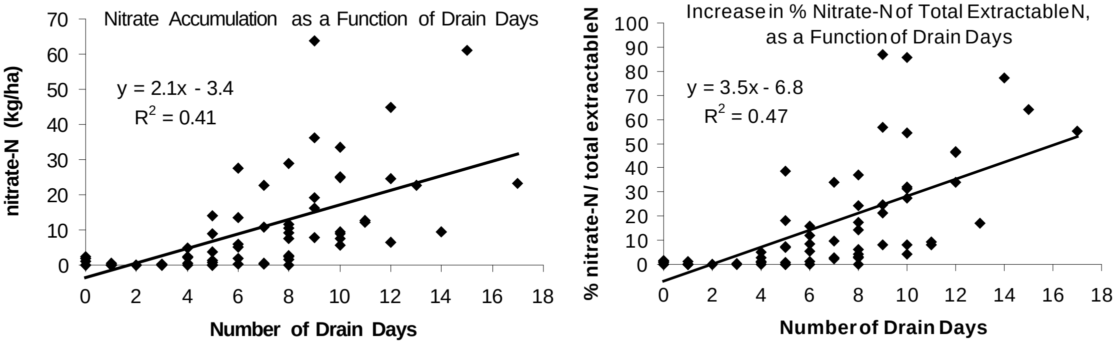

**Figure 5.** Nitrate accumulation in 22 fields as a function of drain days (the first drain day is when the field has completely drained NOT when the grower pulled the boards to drain). Nitrate accumulation is expressed as kg N/ha in the left figure and as the percent of nitrate-N of total extractable N in the right figure.

The 22 fields sampled from are representative of the major rice growing regions across the valley. In order to standardize across fields relative how long a field has been drained the first drain day was when the field had completely drained (there was puddling on the soil surface and the soils were saturated with water); not when the grower pulled the boards to drain the field. Though there was a great degree of variation in both the rate of nitrate accumulation and the total amount accumulated, between 41%-47% of the variation can be explained simply by the number of days a field is subjected to a drain. Averaging across the entire drain period, fields accumulated about 2kg NO3-N/ha/day (Fig. 5).

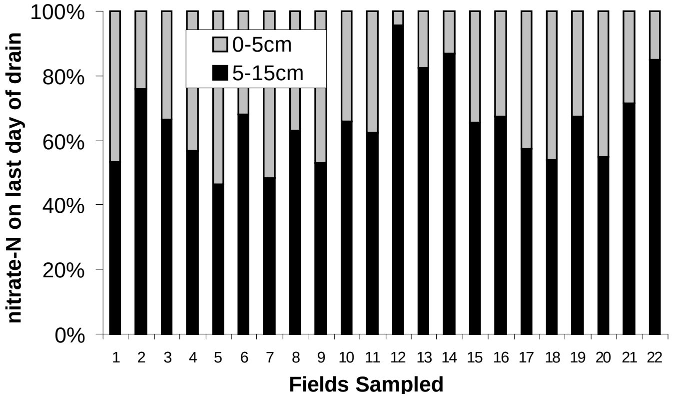

**Figure 6.** Nitrate-N in each field sampled in 2007, split up as a percentage by depth (0-5 and 5-15cm), on the last day of the drain just before reflooding.

On the last day of the drain (or as close as we could sample to it), we split the soil sample into 2 depths to try and increase our understanding of the relative susceptibility of N pools in different depths, to nitrification. Our data showed that equal amounts of nitrate accumulated at each depth. In other words there was consistently about 1/3 the amount of nitrate in the 0-5cm layer as there was in the 5-15cm layer (Fig 6).

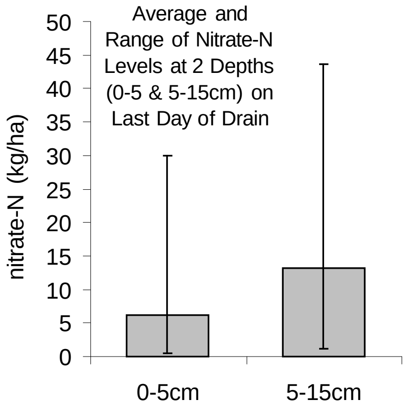

**Figure 7.** Average amount of nitrate-N (kg/ha) accumulated in the 0-5 and 5—15cm depths by the last day of the drain, just before reflooding. The bars represent the range of nitrate values found at each of those depths.

The range of nitrate-N observed by the last day of the drain at both the 0-5 and 5-15cm depths was wide. When averaged across all sites however, the amount of nitrate-N in the 0-5cm and 5-15cm depths is about 6 and 13 kg/ha, respectively, totaling about 20 kg/ha of nitrate-N accumulation on average (Fig. 7). The data indicate that aqua N placed in the subsurface is susceptible to nitrification and nitrate loss.

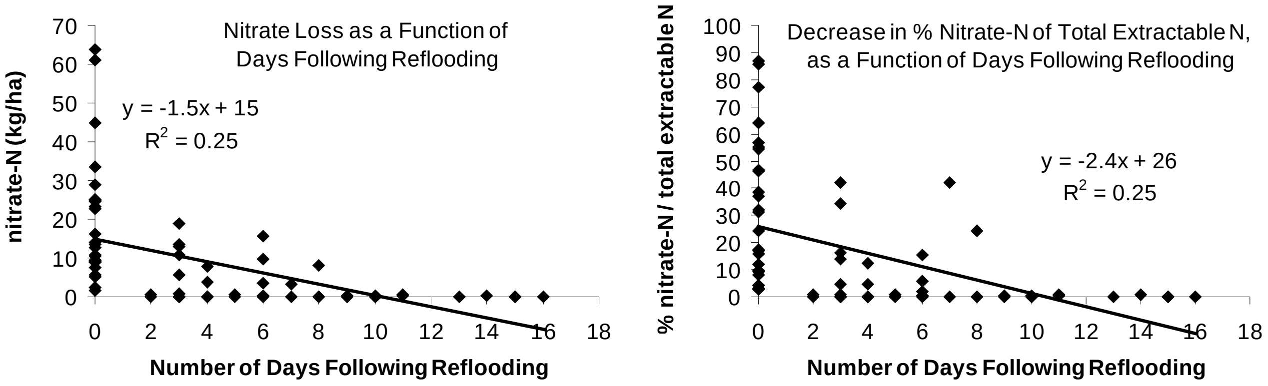

**Figure 8**. Nitrate loss in 22 fields as a function of days following reflooding. Nitrate loss is expressed as kg N/ha in the left figure and as the percent of nitrate-N of total extractable N in the right figure.

Nitrate in the soils following flooding was also measured. Because most growers drain their fields just after seeding, the rice stand is typically not large enough to take up a significant amount of nitrate that accumulates during the drain. Therefore, most of the nitrate that disappears following reflooding is likely lost to the atmosphere through the process of denitrificaiton. The data show that most if not all of the nitrate that accumulates in the soil during the drain is lost by 7 days after reflooding (Fig. 8). Unfortunately there is really nothing growers can do to avoid the loss once nitrate accumulates and is followed by reflooding, making any intervention to reduce nitrate accumulation necessary during the drain period.

*Research Experiment Station Alternative Stand Establishment Studies*

We also repeated the experiments conducted last season at the RES study site. There were several experiments conducted within the RES study site in 2006 which were repeated in 2007. The first made use of the varying early season water management built into the treatments to examine a wide range of weed control strategies (Table 2). In select treatments we again continuously monitored changes in soil moisture and temperature with the use of sensors and data loggers.

The second experiment imposed within the RES was the N rate trial. This marked the 4th year it was repeated and consisted of five N rate sub-plots within each main plot treatment, ranging from 0-200 lb N/acre. This range of N rates has allowed us to generate growth and yield response curves for each of the systems to be constructed. These response curves will provide the information needed to develop efficient N management practices for each system, particularly as growers begin to adopt some of their various components.

Our yield results are consistent with previous years. In the main plots where 50 lb N/ac was applied yields were similar to one another with the exception of the wet seed stale seedbed. This system has consistently yielded lower than the other treatments (Table 2). The most likely reason for this is an N deficiency because when you add sufficient N the yield potential are similar (Fig. 9).

**Table 2.** Rice yields as affected by different establishment practices. All treatments received 150 lb N/ac.

| System | 2004 | 2005 | 2006 | 2007 | Mean 2004-07 |
|---|---|---|---|---|---|
| | | | lb/ac 14% moisture | | |
| WS-conventional | 9511 | 7295 | 7923 | 7171 | 8028$^{A}$ |
| DS-conventional | 9644 | 7509 | 8140 | 7365 | 8218$^{A}$ |
| WS-stale | 8426 | 6555 | 7379 | 7184 | 7386$^{B}$ |
| WS-stale-notill | 9303 | 7299 | 7457 | 8062 | 8030$^{A}$ |
| DS-stale-notill | 9191 | 7404 | 8966 | 8440 | 8500$^{A}$ |
| ANOVA (P value) | ns | ns | ns | ns | 0.0011 |

**2006 Project Objective 2:** To improve N fertilizer guidelines for California rice growers using alternative water management strategies.

The experiments were initiated in 2006 with the long term goal of developing improved N management strategies for growers using alternative early season water management strategies. In these first two years we have established the potential for N losses as well as quantifying those losses and when they are most likely to occur. So far, recommendations can be made to reduce the drain period to as short a period as possible. Every drain day results in about 2 kg NO3-N being formed that is susceptible to loss. The results are encouraging and provide a solid basis on which to begin to test and develop N fertility recommendations to minimize N losses while maintaining rice yields. In 2008 we plan to examine the timing and placement of N fertilizer on growers fields where early drains are used.

Our results are both relevant and of interest to rice growers and PCA's and results have been published as well as presented at a number of meetings this year (see below). Results will be presented at the upcoming winter grower meetings.

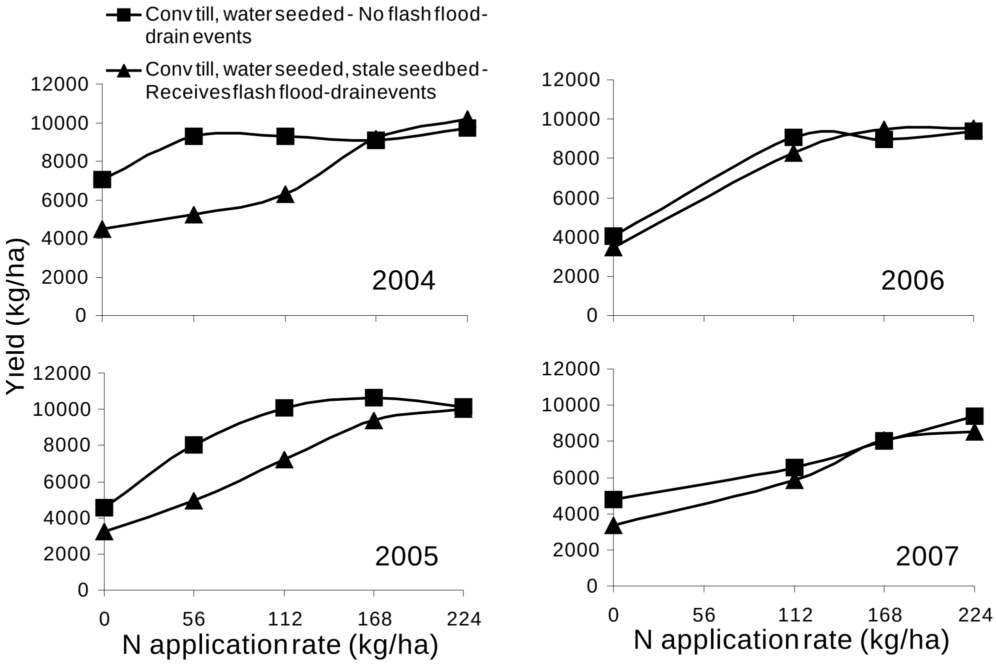

**Figure 9.** Yield response of 2 systems to a range of N application rates from 2004-2007 at the RES systems site.

## Publications and Presentations

Publications:

Linquist, B. A. Fischer, L. Godfrey, C. Greer, J. Hill, K. Koffler, M. Moeching, R. Mutters, and C. van Kessel. 2008. Minimum-till could benefit California rice farmers. California Agriculture 62:24-29.

*Poster presentations:*

Koffler, K., B. Linquist, J. Hill, R. Mutters, C. Greer, and C. van Kessel. 2007. The effects of early season soil drying-flooding cycles on N dynamics and agronomic productivity. American Society of America (ASA) – Crop Science Society of America (CSSA) – Soil Science Society of America (SSSA) International Annual Meetings. New Orleans, LA.

Koffler, K., B. Linquist, J. Hill, L.F. da Silva, C. Mutters, C, Greer, and C. van Kessel. 2007. Linking changes in early season water management to changes in nitrogen dynamics in

California rice systems. California Chapter of American Society of Agronomy – Plant and Soil Conference. Sacramento, CA.

*Oral presentations:*

Koffler, K., B. Linquist, J. Hill, R. Mutters, C. Greer, and C. van Kessel. 2007. The effects of early season soil wetting-drying cycles on N dynamics in California rice agroecosystems. Ecological Society of America (ESA) Annual Meeting held jointly with the Society for Ecological Restoration (SER). San Jose, California.

Koffler, K., B. Linquist, J. Hill, R. Mutters, C. Greer, and C. van Kessel. 2007. Managing nitrogen in alternative rice establishment and weed control systems of California. 4th International Temperate Rice Conference, June 25-28, 2007. Novara, Italy.