PROJECT REPORT

This is a final project report submitted
to the Organic Farming Research Foundation.

Project Title:

Evaluation of nitrogen sources for organic rice production

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Evaluation of nitrogen sources for organic rice production
Bruce Linquist, University of California, Davis. March 2010.

Project Summary

Organic rice is produced on 14,000 ha in the U.S. California is the largest single producer of organic rice worldwide with 6,000 ha, most of which is located in the Sacramento Valley where this study was conducted. In the Northern Sacramento Valley, soils have high clay content and nitrogen (N) fertility has traditionally been applied in the form of poultry litter (PL), due to the inability to grow cover crops under these soil conditions. Recently, a lack of PL availability has forced growers to search for alternative fertilizers. Other sources of organic N fertilizer are available on the market but the efficacy of these fertilizers for rice production, where the rice is grown under flooded, anaerobic conditions, is not known. Therefore, the objective of this study was to evaluate four organic fertilizers (including PL) in regards to (1) their impact on rice yields, (2) nitrogen recovery efficiency, (3) their N mineralization rates under anaerobic conditions, and (4) the economics of their use.

To fulfill the objectives, field trials were conducted using a randomized complete block design in two adjacent fields in 2009. The two fields were managed differently by the grower, which influenced the results. One field was continuously flooded over the course of the growing season (henceforth referred to as CF field). The other field was drained at 25 days after sowing (DAS) and remained dry for one month in an effort to control the weed population (henceforth referred to as drained field). The drained field was then re-flooded at 55 DAS, however the drain period slowed the rice growth and resulted in a delayed harvest.

The trials were planted with an N-responsive rice variety (S-102) and fertilized with four sources of N fertilizer as treatments: poultry litter (PL) (3% N); pelleted feather meal (12% N); pelleted PL and feather meal (6% N); pelleted bone and blood meal (13% N). An unfertilized control (no N) was also used. All N treatments received the same amount of N at 134 kg/ha (120 lb/ac). Organic phosphorus and potassium were applied to all plots to ensure that these nutrients were not limiting. Aboveground biomass, grain yield, plant N-uptake, and soil ammonium-N (NH_4^+-N) were measured at different stages of crop growth. A 60-day anaerobic laboratory incubation with aforementioned fertilizers was conducted to quantify mineralization rates of the organic fertilizers. The incubation was designed as a factorial with five treatments, six sampling events, and four replications. The study was conducted by adding 0.9 mg of N in the form of different fertilizers to 10 g of soil to achieve a rate equivalent to 180 kg N/ha. Tubes were uniformly filled with water, O_2 removed, sealed and placed in an incubator at 25°C. At designated times tubes were analyzed for NH_4^+ by extraction with 2M KCl.

Among the field sites, grain yields (reported at 14% moisture) ranged from 7,055 kg/ha to 10,072 kg/ha. Grain yield in control treatment averaged 7,166 kg/ha and was always significantly lower than the yields in fertilized plots. Pelletized fertilizer response varied across fields but gave on average 25% higher yields than the control plots. Yields in plots fertilized with PL were always lower than the yields of pelletized treatment plots (not significant at $p<0.05$), and always higher than the control plots (significant at $p<0.05$).

Fertilizer N-recovery efficiency (NRE) was calculated as the difference in N uptake between the fertilizer treatment and the control divided by the rate of N applied. In CF field, the

average NRE of pelletized materials ranged from 37-50% while PL had an average NRE of 19%. In the drained field, average NRE of pelletized materials ranged from 25-31%, while PL had an average NRE of 21%. The NRE of fertilizers in the drained field was lower overall than the NRE of fertilizers under a continuous flood. N uptake increased over the course of the growing season in both fields. In the anaerobic laboratory incubation study, N mineralization continued to increase both in the native soil (control) and in the treatments until day 36, after which it slowed. Similarly to what has been shown by others, N mineralization from the native soil N pool followed a two-phase increase where an initial period of rapid N mineralization was followed by a period of slower N mineralization (Olk et al., 1998). Upon subtracting the N mineralized in the control from the treatments, fertilizers also had an initial phase of rapid N mineralization (until day 9) followed by a slower phase of mineralization to 60 days. After 60 days of anaerobic incubation, 13-0-0 had 22% N mineralized, 12-0-0 had 33% N mineralized, 6-3-2 had 26% N mineralized, and PL had only 14% N mineralized. These data indicate that PL, at the rates applied, does not provide sufficient N to meet crop demand, resulting in lower rice yields. The pelletized materials mineralize at a faster rate and thus provide higher yields at similar N rates.

The returns on investment in fertility are high in the CF field (between 57% and 76%), with PL having the lowest increase in profits from fertilizer. These results suggest that an investment in pelletized materials with higher N content may be warranted for CF fields. The returns on investment in fertility were much lower in the drained field (between -18% and 19%) suggesting that investment in fertility may not be worthwhile in the event of an extended drain. Further work is needed to determine the appropriate timing and rate of application of fertilizers in both types of fields in order to develop a better economic analysis.

Introduction to the Topic

Nutrient management presents a major challenge for organic rice growers. In rice systems, most of the fertilizer is applied before planting while some may be applied later in the growing season as a top-dress application. Organic rice farmers have primarily used cover crops and poultry litter (PL) as their sources for basal fertilization. The use of cover crops is problematic as they don't grow well in the poorly drained soils on which rice is typically produced. PL has thus become the primary source of fertility; however, its availability is uncertain, its nutrient composition is variable, and the timing of nutrient release from PL is inconsistent. In conjunction with Lundberg Family Farms we have attempted to address the problem that California organic rice growers have in choosing an efficacious, readily available and consistent method of fertilization.

Since rice is a staple grain crop there has been significant research done on N fertility as relates to its production. The importance of decision-making concerning N management is well documented (Whitworth et al., 2007). We know that soil N-NH_4 and N-NO_3 dynamics are strongly affected by environmental conditions, rate of fertilizer application, and field management (Cavigiolo et al., 2007). As N enters the soil in the form of organic residues, it is converted to a mineralized form which may enter the soil mineral N pool, be immobilized by microbial biomass, or become available to plants. Mineralized N taken up by plants comes from soil native N pools as well as from organic residues/fertilizers that have mineralized. N from native soil pools is thought to provide 50 to 80% of N taken up by rice in soils that are maintained in submerged conditions during the growing season (Broadbent, 1979; Koyama, 1981; Cassman et al., 1996). Thus when using N uptake as a proxy for fertilizer N mineralization, one must be cautious not to confuse mineral N from native soil pools with mineral N from fertilizers. One way to avoid this is to have a zero N control plot that can provide insight into the capacity of the native soil N pool to provide N to growing plants. Despite the challenge of determining whether mineral N is coming from the mineralization of fertilizers or from soil N pools, it is worthwhile to measure plant N uptake since, in combination, extractable N and plant N uptake explain up to 80% of the variation in grain yield (Manguiat et al., 1994).

The rate at which fertilizers mineralize further complicates N management decisions. Fertilizer application to lowland rice fields is often asynchronous with plant N demand (Cassman et al., 1998). In order to achieve high yields, rice plants should have access to an adequate amount of mineralized N before panicle initiation (50-65 days after sowing) regardless of whether the N originates from native soil pools or from the addition of fertilizers. It is particularly challenging to synchronize the delivery of N from fertilizers with plant needs when fertility is applied in organic rather than mineral forms because residues with different compositions can vary greatly in their rate of mineralization and may not provide the appropriate amount of N early enough in the growing season. Rice is a unique crop since it is grown in a flooded environment with anaerobic soil conditions, which has important implications for N mineralization in this agroecosystem. It has been shown that decomposition of organic materials and mineralization of N may be slower under anaerobic conditions (Olk et al., 1998; Witt et al., 2000). However other studies have shown that organic fertilizers can mineralize quickly in flooded conditions and that imitating management practices established for mineral fertilizers can achieve a better use of organic fertilizers (Mouret et al., 2007). The apparent lack of agreement is likely due to the fact that organic sources of N are heterogeneous in composition and vary in N content; samples taken from the same batch of farmyard manure may exhibit net N immobilization or net N mineralization (Van Kessel and Reeves, 2002). This study attempts to sort out these inconsistencies by exploring mineralization rates of organic N fertilizers and plant N uptake in an anaerobic laboratory incubation, in a continuously flooded organic rice field, and in an organic rice field drained for weed control with aerobic conditions lasting for one month.

Objectives

The objective of this study was to evaluate four organic fertilizers in regards to:
(1) their impact on rice yields,
(2) nitrogen recovery efficiency,
(3) their N mineralization rates under anaerobic conditions
(4) the economics of their use.

Materials and Methods

Field Trials

Field trials were conducted in two adjacent organically certified fields. The trials were planted with an N-responsive rice variety (S-102) and fertilized with four sources of N fertilizer as treatments: poultry litter (PL) (3% N); pelleted feather meal (12% N); pelleted PL and feather meal (6% N); pelleted bone and blood meal (13% N). An unfertilized control (no N) was also used. The N concentration was calculated on a dry weight basis and the volume of material applied reflected the difference in N content of each treatment. For basal field trials, all fertilizers were surface-applied prior to seeding and lightly incorporated. Phosphorus and potassium were applied to all plots to ensure that these nutrients were not limiting. All N treatments were applied at a rate of 134 kg/ha (120 lb/ac).

Aboveground biomass (AGB) was determined by harvesting and weighing one meter squared of plant material, subsampling, weighing and drying, then weighing the subsample. AGB was determined at 24-25 days after sowing (DAS), at panicle initiation (53 DAS), and at harvest. Plant tissues were ground and analyzed for total N content at the UC-Davis Stable Isotope Facility using the Kjeldahl method (Bremner and Mulvaney, 1982). Fertilizer N-recovery efficiency (NRE) was calculated as the difference in N uptake between the fertilizer treatment and the control divided by the rate of N applied.

Grain yield was determined by removing grain from harvested subsamples, drying it to constant weight, and calculating the yield in kg/ha. Soil mineral N was measured at 24-25 DAS and at panicle initiation (53 DAS) by taking eight subsamples of soil with a small Dutch auger in each experimental plot. The saturated soils were kept on ice and extracted with 2M KCl directly upon returning to the lab. Extractable NH_4-N was determined using a procedure adapted from Forster (1995) and Verdow et al. (1977). NO_3-N was measured in the drained field only since we would only expect to see it under aerobic conditions and because it is so rapidly mobilized. NO_3-N was determined using a procedure adapted from Miranda et al. (2001) and Doane and Horwath (2003).

The two fields were managed differently by the grower which affected the results. One field was continuously flooded (CF) over the course of the growing season. The other field was drained at 25 days after sowing (DAS) and remained dry for one month in an effort to control the weed population. The drained field was then re-flooded at 55 DAS; however, the drain period slowed the rice growth and resulted in a delayed harvest (three weeks later than the CF field).

Anaerobic Incubation

In order to quantify mineralization rates of the organic fertilizers under flooded conditions, a 60-day anaerobic incubation was conducted in the laboratory. The incubation was designed as a factorial with five treatments, six sampling events, and four replications. 10 g of air-dried soil and 5 g of K^+ saturated cation-exchange resins was weighed into acid-washed 200 mL bottles with rubber gasket caps. Fertilizer treatments were applied to the bottles for an equivalent of 180 kg N/ha. Since different treatments had different percent N, the added weights were as follows: 1) PL 30 mg; 2) feather meal 7.5 mg; 3) PL and feather meal 15 mg; 4) bone and blood meal 6.9 mg, and 5) control 0 mg. The soil, resin, and fertilizers were mixed uniformly by tilting and gently tapping the bottles against the lab bench. Tubes were filled with 60 mL of deionized water and flushed for 30 s with a gas mixture of 95% N_2 and 5% CO_2. Next the bottles were capped, sealed with parafilm, and placed in an incubator at 25^{o}C. At designated times (0, 9, 18, 36, and 60 days after incubation), bottles were removed from the incubator, parafilm was removed, and the bottles were extracted with KCl. Each bottle received 60 mL of 4M KCl and was put on a shaker for one hour then allowed to settle overnight. The next day, 20 mL of the supernatant was extracted and saved in acid-washed 50mL tubes for NH_4-N determination. The remaining solution was carefully removed from the bottle using a vacuum and the bottle was weighed in order to ascertain how much solution remained mixed with the soil and resin at the bottom. Next the bottle received an additional 100 mL of 2M KCl for a second extraction. Following one hour of shaking and approximately two hours of settling, 20 mL of the supernatant was removed and saved in acid-washed 50 mL tubes for NH_4-N determination. Extractable NH_4-N was determined using a procedure adapted from Forster (1995) and Verdow et al. (1977).

Statistical analyses

Effects of fertilizer treatments on grain yield, N uptake, nitrogen recovery efficiency (NRE), and soil mineral N at each site were evaluated by standard analysis of variance (ANOVA) using SAS 9.1. Anaerobic incubation was analyzed as a 5x6 factorial in a standard ANOVA using SAS 9.1. All mean separations were determined using a protected LSD.

Results

Table 1. Soil characteristics.

Soil	Organic Matter (%)	Organic Carbon (%)	TKN (%)	NO_3-N (ppm)	Ex-K (ppm)	Olsen-P (ppm)
CF Field	2.22	1.29	0.12	5.88	74	5.8
Drained Field	2.13	1.23	0.12	10.68	81	10

Table 2. Fertilizer properties and nutrient concentrations.

Fertilizer	Total P (%)	Total K (%)	Organic Carbon (ppm)	Total Carbon (%)	TKN (%)	Organic Matter (%)	C:N
13-0-0	1.0	0.23	54	46	12.96	93.1	3.55
12-0-0	0.41	0.42	55	47	13.02	95.1	3.60
6-3-2	1.4	1.65	40	34	6.69	69.3	5.05
Poultry litter	1.4	2.28	36	27	3.16	62.6	8.64

Grain yield and biomass in basal fertilizer trials

There was a significant yield response to all fertilizers in both fields. Rice grain yield from basal fertilizer field trials was not significantly different between treatments; however, all treatments had significantly greater yields than control plots in both fields. Average yields ranged from 7,276 kg/ha to 9,121 kg/ha in the drained field and from 7,055 kg/ha to 10,049 kg/ha in the CF field.

Figure 1. Biomass and grain yield at harvest in drained field. All fertilizers performed significantly better than the control at $p<0.05$; however, differences were not significant between fertilizers for biomass and grain yield.

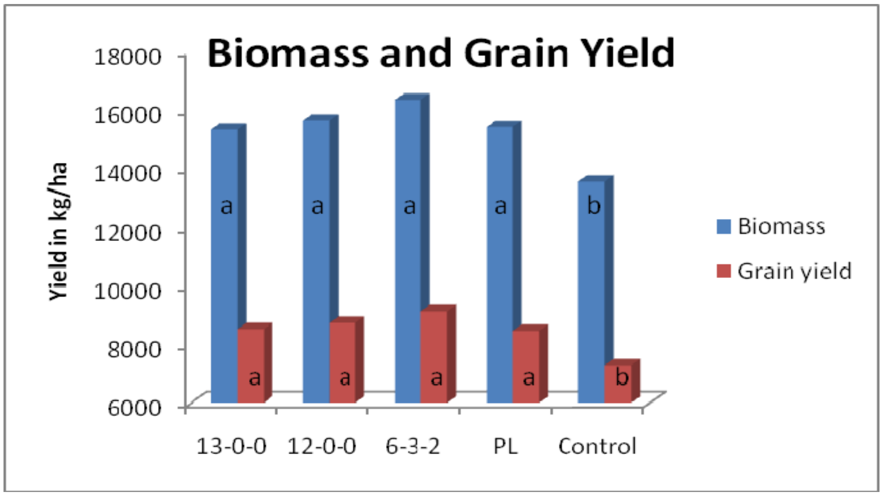
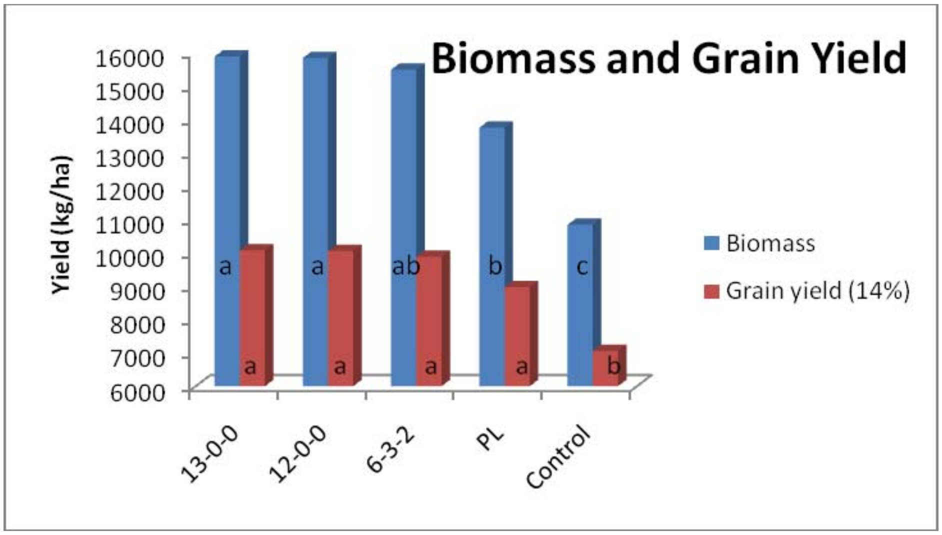


Figure 2. Biomass and grain yield at harvest in the CF field. All fertilizer treatments have significantly higher biomass and grain yield than control plots. While there are no significant differences between fertilizer treatments in grain yield, there are differences in biomass; this is due to the significant differences in harvest index between fertilizer treatments. Differences significant at $p<0.05$.



Nitrogen dynamics in basal fertilizer trials

In the CF field, average NRE of pelletized materials ranged from 37-50% while PL had an average NRE of 19%. In the drained field, the NRE of pelletized materials ranged from 25-31% while PL had an average NRE of 21%. The NRE of pelletized fertilizers in the drained field was lower overall than the NRE of pelletized fertilizers under a continuous flood while PL performed similarly in both field types.

Figure 3. N recovery efficiency (NRE) as measured in the drained field by subtracting N uptake in control plot from N uptake in treatment plot and dividing by N rate applied.
Differences are not significant at $p<0.05$.

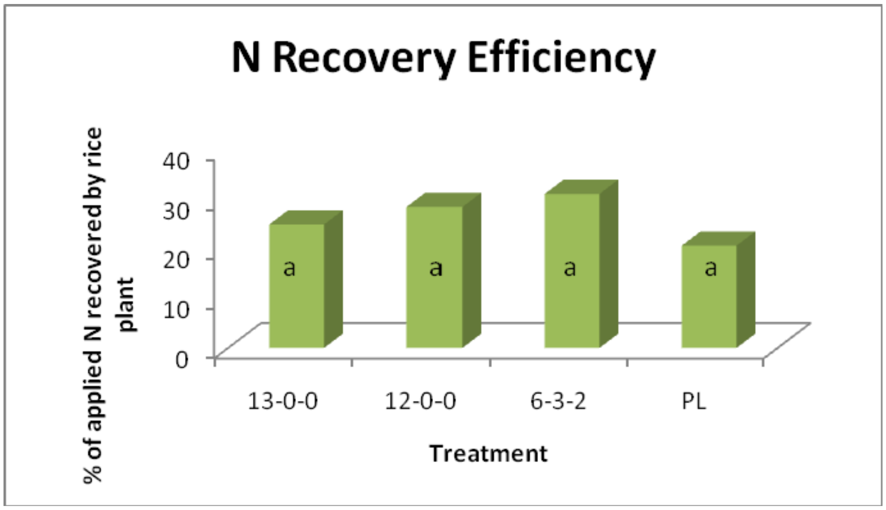
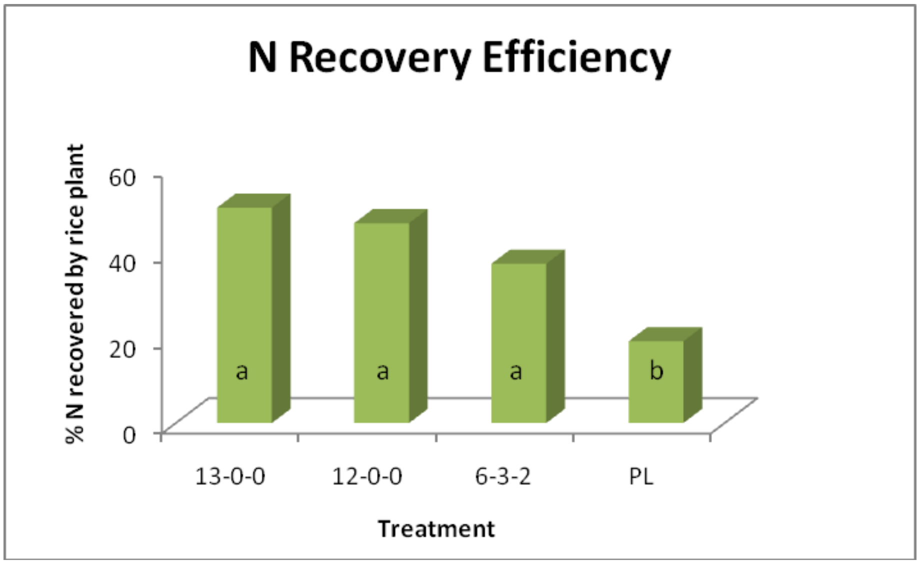


Figure 4. NRE as measured in the CF field by subtracting N uptake in control plot from N uptake in treatment plot and dividing by N rate applied. Differences are significant at $p<0.05$.



N uptake increased over the course of the growing season in both fields; however, the rate at which N uptake increased differed between the fields due to differences in water management practices. In the continuously flooded (CF) field, the increase in N uptake between 25 and 53 DAS ranged from 60 to 115 kg/ha while it only increased 3-12 kg/ha between 53 DAS and harvest. This would suggest that in the CF field rice plants are taking up available N prior to 53 DAS or panicle initiation. In the drained field, the increase in N uptake ranged from 36 to 68 kg/ha between 24 and 53 DAS and ranged from 52 to 77 kg/ha between 53 DAS and harvest. The extended drain is stressful to rice plants (see photos in appendix B) and the plants are unable to efficiently take up available N during this period (between 24 and 53 DAS), which is why we see an accumulation of NO_3^- in the soil (see Table 3). The physiological delay in growth may have caused the plants in the drained field to continue taking up available N after 53 DAS (panicle initiation was delayed) whereas N uptake plateaued at this stage for plants in the CF field. N Uptake and NRE for all fertilizers were adversely affected by draining and re-flooding the field. In comparing differences in N uptake between treatments, PL had the lowest N uptake of all fertilizers in both fields at all sampling points. This is likely translated to a lower yield potential but we did not see this reflected in our data due to high initial N concentrations in the soil.

Figure 5. N uptake in kg/ha as measured at 24 DAS, 53 DAS, and at harvest in the drained field. Differences are significant at $p<0.05$.

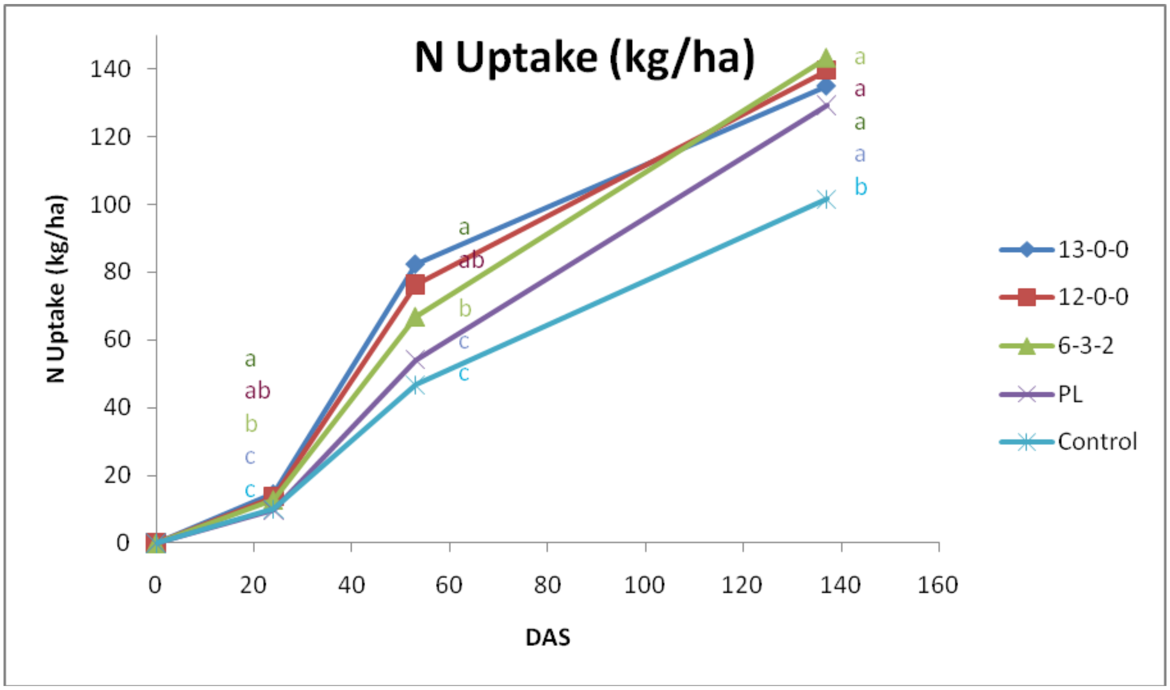
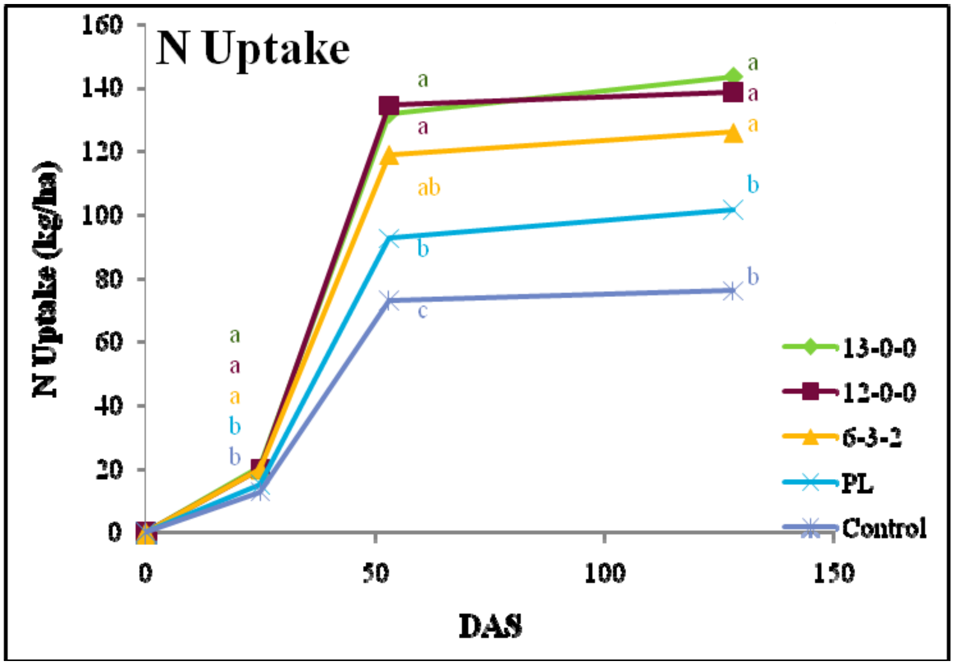


Table 3. Soil mineral N in the drained field at 24 and 53 DAS.

	NH_4 (µg N/ mg soil)	**NH_4** **(**µg N/ mg soil)	**NO_3** (µg N/ mg soil)
Treatment	**24 DAS**	**53 DAS**	**53 DAS**
13-0-0	17.5	2.4	16.4
12-0-0	31.2	2.9	21
6-3-2	15	2.3	18
PL	12.5	2.3	7.4
Control	7.9	1.7	4.3

Figure 6. N uptake in kg/ha as measured at 25 DAS, 53 DAS, and at harvest in the CF field. Differences are significant at $p<0.05$.



Anaerobic incubation measuring N mineralization

In the anaerobic laboratory incubation study, N mineralization continued to increase both in the native soil (control) and in the treatments until day 36, after which it slowed. Similarly to what has been shown by others, N mineralization from the native soil N pool followed a two-phase increase where initial N mineralization was rapid, followed by a period of less N mineralized (Olk et al., 1998). Upon subtracting the N mineralized in the control from the treatments, fertilizers also had an initial phase of rapid N mineralization (until day 9) followed by a slower phase of mineralization to 60 days. After 60 days of anaerobic incubation, 13-0-0 had 22% N mineralized, 12-0-0 had 33% N mineralized, 6-3-2 had 26% N mineralized and PL had only 14% N mineralized. While PL had early rapid mineralization in the anaerobic incubation, this was followed by a slower mineralization rate relative to other fertilizers. This would suggest that mineral N from PL is unavailable between tillering and panicle initiation, the period at which rice plants under flooded conditions are most actively taking up N. The pelletized materials tend to mineralize at a faster rate and thus may provide higher yields at similar N rates.

Figure 7. N mineralized over time in anaerobic incubation.

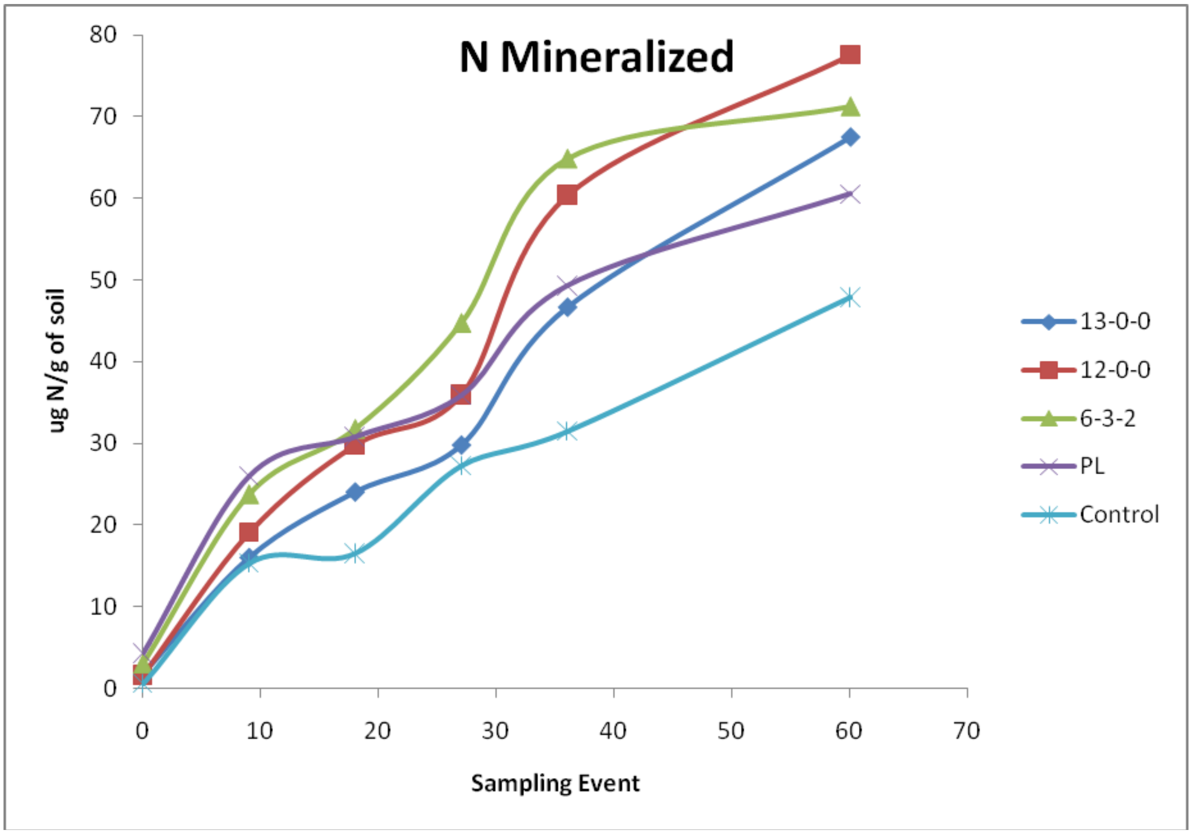
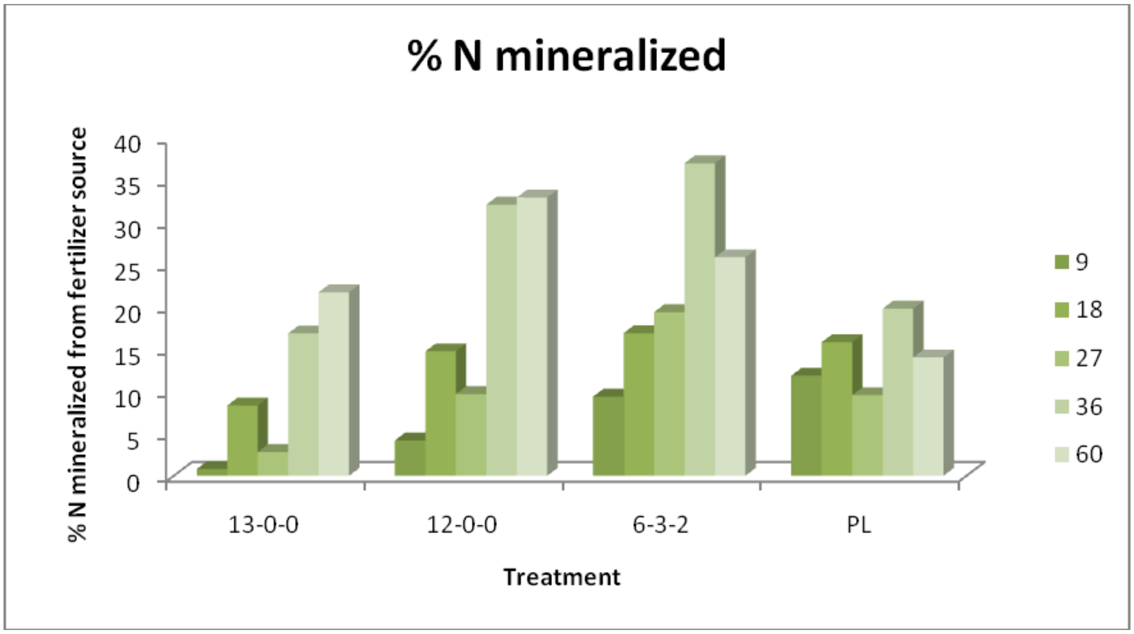


Table 4. N mineralized by treatment and sampling event. Differences are significant at $p<0.05$.

Treatment	Day 0	Day 9	Day 18	Day 27	Day 36	Day 60
13-0-0	bc	bc	a	b	b	ab
12-0-0	bc	abc	a	ab	a	ab
6-3-2	ab	abc	a	ab	a	ab
PL	ab	abc	a	ab	b	b
Control	c	c	b	b	c	c

Figure 8. % N mineralized over time in anaerobic incubation



(% N mineralized calculated as $\frac{Treatment\ N - Control\ N}{N\ rate\ applied}$)

Table 5. % N mineralized by treatment and sampling event. Differences are significant at $p<0.05$.

Treatment	Day 9	Day 18	Day 27	Day 36	Day 60
13-0-0	c	a	b	b	ab
12-0-0	bc	a	ab	a	a
6-3-2	ab	a	a	a	ab
PL	a	a	ab	b	b

Economic analysis of fertilizers

Returns on investment for each field were calculated on a partial basis, only including costs and returns associated with fertility (i.e. cost of fertilizer, application cost, and yield response to fertilizer). Profit increase from fertilizer addition can be compared within fields only, not between fields. In determining cost of fertilizer per acre ($/ac), differences in volume applied due to differences in N content of fertilizers were accounted for. Also N content of PL was calculated on a dry weight basis when determining which volume of PL would yield a rate of 120 lbs N/ac. Cost of fertilizer application by spreading was $10/ac for 13-0-0 and 12-0-0. This was increased to $15/ac for 6-3-2 to account for the additional volume required to achieve the target N rate applied. Cost of PL application is included in the cost of material as it is the convention for the supplier to deliver and spread it. It should be noted that this relieves the grower of the additional task of arranging for product delivery and application (not reflected in monetary costs).

The returns on investment in fertility are high in the CF field with PL having the lowest increase in profits from fertilizer. These results suggest that an investment in pelletized materials with higher N content may be warranted for CF fields. In the drained field, 13-0-0 and 12-0-0 had negative returns on investment due to low yields and the high price of these products. PL had positive but low returns on investment while 6-3-2 had higher returns on investment relative to other fertilizers due to higher yields in that treatment (ns at $p<0.05$).

Table 6. Cost of materials.

Fertilizer	Cost/ton of material	% N	Cost/ lb of N
13-0-0	725.00	13	2.79
12-0-0	690.00	12	2.88
6-3-2	325.00	6	2.71
PL	105.00	3.28	2.12

Table 7. Returns on investment in fertility in drained field.

Fertilizer	**Revenue Increase** ($/ac)	**Cost Increase** ($/ac)	**Profit increase** ($/ac)	**Returns on investment (%)**
13-0-0	308.29	377.34	-69.05	-18
12-0-0	361.57	393.38	-31.82	-8
6-3-2	461.04	388.94	72.10	19
PL	292.98	285.55	7.43	3

Table 8. Returns on investment in fertility in CF field.

Fertilizer	**Revenue Increase** ($/ac)	**Cost Increase** ($/ac)	**Profit increase** ($/ac)	**Returns on investment (%)**
13-0-0	754.32	429.69	324.62	76
12-0-0	748.29	439.44	308.85	70
6-3-2	705.15	419.86	285.29	68
PL	478.26	305.22	173.04	57

Discussion

In the field trials there was little yield response to N because both fields had high N content at the beginning of the season (see Table 1). This is confirmed by the relatively high yields in the control plots. While the average yield of control plots was higher in the drained field than in the CF field, the CF field had higher yields in treatment plots. This may be due to the change in N dynamics created by the extended drain which had a negative impact on N uptake, NRE, and therefore yield in fertilized plots.

Under anaerobic conditions organic N is mineralized to NH_4 which may be immobilized by microbial biomass, may enter the soil mineral N pool, may volatilize to NH_3, or may be taken up by plants. When the field is drained due to weed pressure, much of the NH_4 is converted to NO_3 which is highly soluble in water. Indeed at 53 DAS, levels of NO_3 were 3-7 times greater than levels of NH_4 (see Table 3). This NO_3 may be available to plants, however the plants are under physiological stress due to the lack of water and are unable to take it up. This is reflected in low plant N uptake measured at 53 DAS and high levels of NO_3 measured in the soil. If NO_3 is not taken up by plants, it will be lost to groundwater or denitrification upon re-flooding which explains the relatively low NRE seen in this field.

The low NRE in the drained field translates into a decreased yield. Due to the depression in yield, revenue is decreased and the returns on investment in fertilizer are very low. These results suggest that investment in fertility may not be worthwhile in the event of an extended drain since the returns are so low. However it is difficult for growers to predict at the beginning of the season whether they will need to drain a field due to weed pressure. In the CF field, returns on investment in fertilizer were positive and suggest that purchasing additional fertility may be warranted in fields under a continuous flood. However further work is needed to determine the appropriate timing and rate of application of fertilizers in fields under both types of management practices. This will lead to a more refined economic analysis.

Outreach

To date the findings from the project have been disseminated in the form of posters at the 2009 Rice Field Day at the Rice Experiment Station in Biggs, CA, and at the 2010 Rice Technical Working Group Annual Meeting in Biloxi, MS. Results have been presented at winter rice grower meetings in Yuba City, Richvale, and Glenn, CA. Also results will be presented at a grower meeting organized by Lundberg Family of Farms which will address the majority of organic rice growers in California. We will present the findings in a talk at the annual meeting of the American Society of Agronomy in November 2010. Also we are in the process of publishing the findings in a peer-reviewed journal. The findings will also be compiled in the form of a Masters of Science thesis to be submitted in 2010.

Leveraged Resources

The student running the project was able to secure a Research Assistant Fellowship from UC-Davis Plant Sciences Department that offset the cost of her salary (which would have been paid for in part by the OFRF grant). Also the Lundberg Family of Farms generously contributed by purchasing the fertilizer treatments, providing labor for application and sampling, and helping to secure a field site for the experiment.

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Appendix A: Results Tables

Table 9. Biomass measured in drained field at 24 DAS, 53 DAS and at harvest, with significant differences at $p<0.05$.

Treatment	24 DAS	24 DAS (kg/ha)	53 DAS	53 DAS (kg/ha)	Harvest	Harvest (kg/ha)
13-0-0	a	479	a	3038	a	15309
12-0-0	ab	455	ab	2820	a	15630
6-3-2	b	433	bc	2518	a	16328
PL	c	361	c	2138	a	15399
Control	c	372	c	2105	b	13547
LSD	40		456		1193	

Table 10. Grain yield as measured in drained field at harvest.

Treatment	Grain yield (14%)	Grain yield (14%) (kg/ha)
13-0-0	a	8510
12-0-0	a	8723
6-3-2	a	9121
PL	a	8448
Control	b	7276
LSD	963	

Table 11. Biomass, harvest index, and grain yield in CF field at harvest. All fertilizer treatments have significantly higher biomass and grain yield than control plots. While there are no significant differences between fertilizer treatments in grain yield, there are differences in biomass; this is due to the significant differences in harvest index between fertilizer treatments.

Treatment	Biomass	Biomass (kg/ha)	Harvest Index	Harvest Index	Grain yield (14%)	Grain yield (14%) (kg/ha)
13-0-0	a	15877	b	0.55	a	10073
12-0-0	a	15834	b	0.56	a	10049
6-3-2	ab	15483	ab	0.56	a	9876
PL	b	13746	ab	0.57	a	8968
Control	c	10837	a	0.57	b	7055
LSD	1884		0.0144		1173	

Table 12. N Uptake in drained field with significant differences at $p<0.05$.

Treatment	24 DAS	24 DAS (kg/ha)	53 DAS	53 DAS (kg/ha)	Harvest	Harvest (kg/ha)
13-0-0	a	14.58	a	82.37	a	134.94
12-0-0	ab	13.74	ab	76.30	a	139.65
6-3-2	b	12.86	b	66.85	a	143.20
PL	c	9.61	c	54.14	a	129.19
Control	c	10.00	c	46.67	b	101.54
LSD	1.45		11.34		19.262	

Table 13. NRE in drained field with no significant differences between treatments.

Treatment	N Recovery Efficiency	%N recovered
13-0-0	a	25
12-0-0	a	28
6-3-2	a	31
PL	a	21
LSD	ns	

Table 14. NRE in CF field. PL has a significanlty lower NRE than other fertilizer treatments.

Treatment	N Recovery Efficiency	%N Recovered
13-0-0	a	50
12-0-0	a	47
6-3-2	a	37
PL	b	19
LSD	15.668	

Table 15. N Uptake in CF field with significant differences at $p<0.05$. Data from samples taken at 25 DAS and 53 DAS did not fit the assumptions of the ANOVA and had to be transformed. The de-transformed means are shown below. Differences are significant at $p<0.05$.

Treatment	25 DAS	25 DAS (kg/ha)	53 DAS	53 DAS (kg/ha)	Harvest	Harvest (kg/ha)
13-0-0	a	20.17	a	131.64	a	143.37
12-0-0	a	19.23	a	134.26	a	138.50
6-3-2	a	19.46	ab	118.87	a	125.79
PL	b	14.72	b	92.38	b	101.49
Control	b	12.46	c	72.85	c	75.85
LSD	*		*		20.886	

Appendix B: Photos from project

Fertilizers used as treatments in field trial and incubation.

Applying fertilizers to basal field trials.

Comparison of rice plants from drained field (left) and CF field (right) at 53 DAS after one month of aerobic, drained conditions.

Drained field at 53 DAS. Taking soil samples prior to reflooding.

CF field at 53 DAS, plants are at panicle initiation.

A comparison of fields under different management practices (drained on left, CF on right). Top photo taken at 53 DAS. Bottom photo taken at harvest. Note high weed density in drained field.

Experimental units for anaerobic incubation.