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COMPREHENSIVE RESEARCH ON RICE
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PROJECT TITLE: Reassessing Soil N Availability and Fertilizer Recommendations Under Alternative Rice Residue Management Practices.

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OBJECTIVE AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

1. **To assess changes in nitrogen availability as affected by alternative residue management practices in rice cropping systems.**

2. **To reevaluate nitrogen fertilizer recommendations and optimize nitrogen use efficiency in winter flooded and non-flooded rice cropping systems.**

In 1998 three field sites were utilized to examine N cycling in California rice under alternative straw management practices. The two main field sites are on-going rice straw residue management trials located in Maxwell, CA on a Willows Clay and Biggs, CA on a Stockton Adobe. The Maxwell and Biggs sites have large field-scale plots representing different rice straw residue treatments including burning, incorporation, winter flooding and winter fallow without flooding (Maxwell 1.3 ha, Biggs 0.5 ha). The plots are managed with agronomic practices typical for California rice production (i.e., tillage, burning, flooding, fertility, and pests). The Maxwell site is currently in its 6th season of straw treatments and the Biggs site is in its 5th season. Added in 1998, the third site is located in Yuba County on a field that had rice straw incorporation and winter flooding. The Yuba site was chosen to compare nitrogen use efficiency on a red earth soil (Yo series) with the two existing and clay-rich soils. Soil properties of these three soils are shown in Table 1. Notable differences among the soils include clay content, total N, exchangeable K, and EC. The diverse array of soils provides for more universal understanding of N availability and fertilizer use efficiency for rice in California.

Microplots were established at all three field sites using fertilizer labeled with ^{15}N. Use of ^{15}N fertilizer allows for the precise tracking of N as it cycles through the soil, plant and residue. At the Maxwell and Biggs sites, microplots were established in the following four treatments: 1) residue incorporated and winter flooded, 2) residue burned, winter flooded, 3) residue incorporated, non-winter flooded and, 4) residue burned, non-winter flooded in all four repetitions of the main field study. These four residue management treatments were chosen as they represent the most diverse residue management options that are currently been tested. Microplots were established in May 1997 at Maxwell and in May 1998 at Biggs. Both sites received the added subplots prior to the 5th growing season of the straw management trials. The Maxwell microplots are 12 m^2 , while those at Biggs were 1.83 m^2 in size. The Yuba site received ^{15}N in June 1998 in four, 2.25 m^2 microplots; and did not compare straw treatments.

At the Maxwell and Biggs sites, enriched urea fertilizer (^{15}N, 9.99 % atom excess) was uniformly applied to microplots at a rate of 0.2 g of ^{15}N per meter just prior to planting in a dilute water solution. At the Maxwell site, a nitrification inhibitor was applied with the N fertilizer (N-Serve 24E, nitrapyrin: 2-chloro-6-(trichloromethyl) pyridine- Dow-Elanco, Indianapolis, IN) at a half-strength field rate of 0.4 L ha^{-1} to reduce losses of applied N during the few days prior to flooding. The Maxwell site was mechanically incorporated immediately following application, while at the Biggs site the microplot fertilizer was hand incorporated. Metal barriers were placed around the exterior of the microplots at both sites to a soil depth of 0.3 m to reduce lateral flow and dilution of the applied fertilizer N. The Yuba site received enriched urea fertilizer (^{15}N, 4.46 % atom excess) was uniformly applied to microplots at a rate of 0.1 g of ^{15}N per meter just prior to planting in a dilute water solution. At the Yuba site the microplot fertilizer was hand incorporated and plot borders were not installed.

Table 1. Soil chemical and physical characteristics at three field sites 1998 (0-15 cm depth).

Soil Parameter		Maxwell	Biggs	Yuba
Texture		Willows Clay	Stockton Adobe	Yo
Clay	%	51	35	23
Silt	%	44	48	64
Sand	%	5	17	13
pH		6.6	4.7	4.7
EC	$dS\ m^{-1}$	1.4	0.4	0.14
CEC	$cmol\ kg^{-1}$	42	30	22.5
total C	$g\ kg^{-1}$	19.5	12.3	8.5
total N	$g\ kg^{-1}$	1.7	1.0	0.7
P - Olsen	$mg\ kg^{-1}$	11.3	11.1	6.2
Exchangable K	$mg\ kg^{-1}$	305	72	200
Ca	$meq\ L^{-1}$	1.6	1.2	0.3
Mg	$meq\ L^{-1}$	1.2	1.0	0.2

Straw residue management in the microplots for the incorporated treatments was accomplished using a small-scale chopper and tiller to simulate field-scale operations while conserving the integrity of the microplots. Straw residue on the burned microplots was removed for accompanying studies and replaced with equivalent amounts of unlabeled rice straw from the adjacent main plots. Microplots were harvested with a micro-plot combine-harvester at the Maxwell site and hand harvested at the Biggs and Yuba sites. All other agronomic operations on the microplots were accomplished using field-scale equipment.

Soil and plant samples were taken from the main and microplot areas at the three field sites. Soil samples were taken every two months throughout the year while samples for plant N determination were taken approximately every 3 weeks throughout the growing season. Soil samples were stored at 4°C and analyzed within 3 days. Inorganic N (NO_3^- and NH_4^+) was extracted with 2 N KCl (5:1 extractant to soil) and determined on an auto-analyzer (Lachat, Mequin, WI). Labeled inorganic N (NO_3^- and NH_4^+) diffused onto Whatman GF filter paper for ^{15}N analysis (Stark and Hart, 1996).

Microbial biomass determinations were done using the Chloroform-Fumigation Incubation method. The movement of ^{15}N labeled fertilizer into microbial biomass was analyzed according to Stark and Hart (1996) and Horwath and Paul (1994). Additional soil sample was air at 25°C, and finally ball milled. Plant samples were separated into shoots and roots, dried at 60°C and ball-milled. Labeled and total N in soil and plant samples was determined on a Gas Chromatograph-Mass Spectrometer (Europa Scientific, Crewe, England).

The conversion from pounds per acre to kilograms per hectare is essentially equivalent (1.0 lbs. $Acre^{-1}$ = 1.12 kg ha^{-1}); and ug cm-3 is essentially equivalent to kg ha-1 (1ug cm^{-3} = 1.5 kg ha^{-1} to 15 cm depth).

All funds necessary for the stable isotope ^{15}N research was made possible by the CA Rice Research Board. The funds that support the straw management trials at Maxwell and Biggs was provided by the CA Energy Commission and Ducks Unlimited.

SUMMARY OF 1998 RESEARCH RESULTS BY OBJECTIVE

OBJECTIVE 1: To assess changes in nitrogen availability as affected by alternative residue management practices in rice cropping systems.

Winter flooding has consistently increased straw decomposition without impacting rice yield at the Maxwell and Biggs research sites. However, the long-term impacts of rice straw decomposition can not be evaluated with limited short-term studies. Organic matter additions and winter flooding will affect nitrogen immobilization and mineralization process. Initially, the high C to N ratio rice straw may immobilize N. After many years of residue incorporation, a large pool of soil organic matter may build up and supply mineral N through mineralization processes. We examined available N at both Maxwell and Biggs sites.

Available soil inorganic N at both the Maxwell and Biggs site was similar. During the winter and summer flood periods, the dominant form of mineral N was ammonium. During the drained periods the dominant form of N was nitrate. Values for Maxwell are shown in Fig. 1 and are expressed as total inorganic N. At Maxwell, winter flooding produced higher amounts of soil inorganic N both during the growing season and the spring. Incorporation of residues decreased available inorganic N just prior to winter flooding due to N immobilization; and resulted in more inorganic N just prior to planting. Winter flooding resulted in greater amounts of fertilizer ^{15}N available in mid-season and in the fall prior to winter flooding (Fig. 2). Winter flooding has produced higher inorganic N concentrations in multiple years of the study. At the Biggs site, winter flooding also produced greater amounts of inorganic N in the spring 1998 (Fig. 3). It can be assumed that the nitrate N would be lost following flooding of the newly seeded crop. This essentially means that most of the available N that accumulated following winter was lost to denitrification.

Figure 1. Maxwell Site: Available soil inorganic N under burned and incorporated straw management (0-15 cm depth).

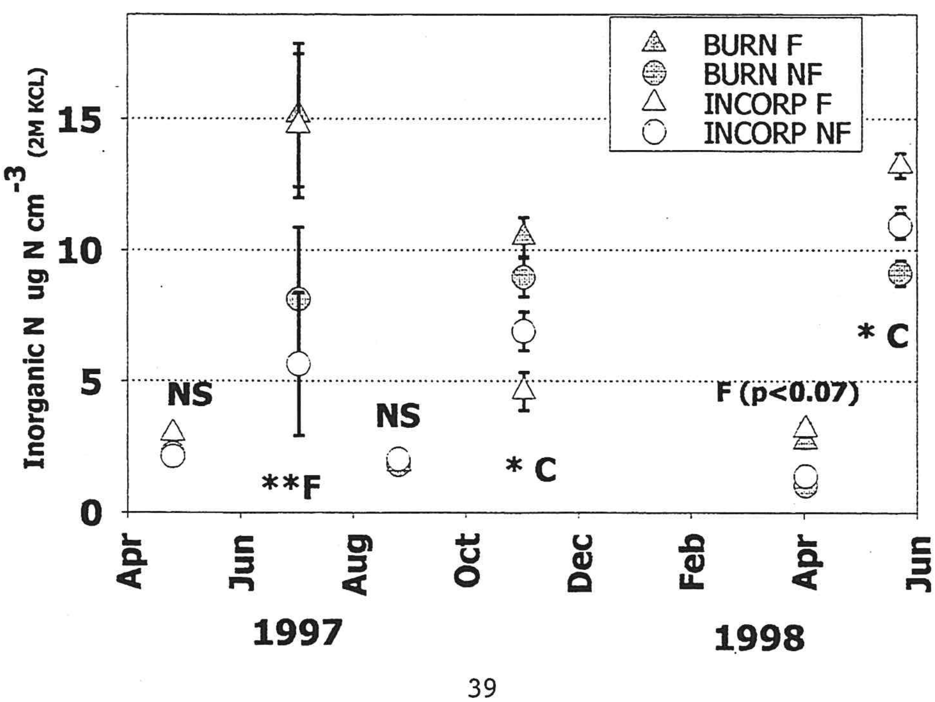


Figure 2. Maxwell Site: ^{15}N Fertilizer recovery as available soil inorganic N. Average values presented for burned and incorporated treatments for 0-15 cm depth . ^{15}N fertilizer applied in May 1997. Percentage values refer to percent of ^{15}N recovered either as percent of fertilizer applied (fert.) or that remaining in soil (soil).

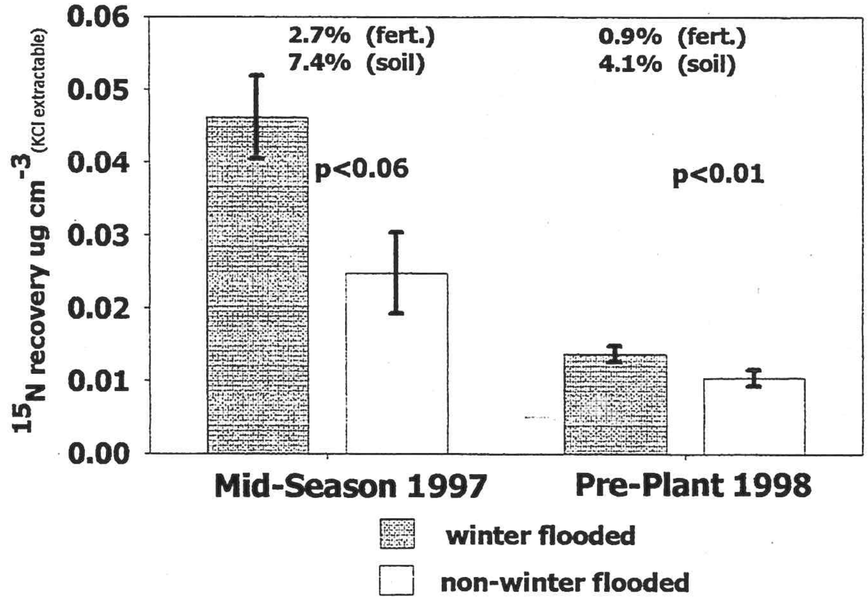
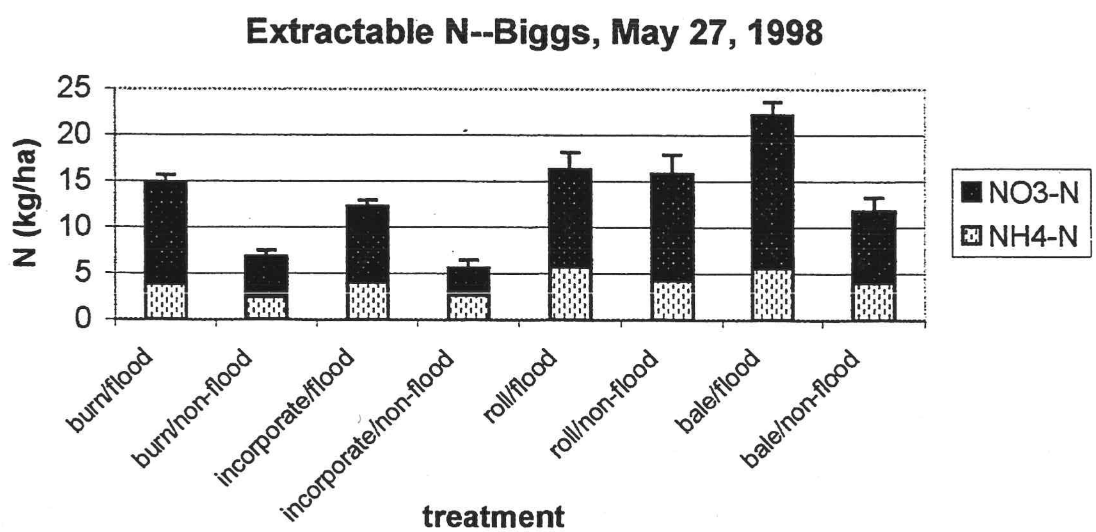


Figure 3. Biggs Site: Available soil inorganic N under alternative rice straw managements (0-15 cm depth).



{error bars=standard error of total N}

OBJECTIVE 2: To reevaluate nitrogen fertilizer recommendations and optimize N use efficiency in winter flooded and non-flooded rice cropping systems.

Fertilizer nitrogen availability trials and plant nitrogen uptake use efficiency was done through the use of ^{15}N labeled nitrogen (stable isotope). The use of labeled nitrogen permitted us to follow the fate of fertilizer nitrogen under the different straw management practices. The amount of labeled fertilizer N was quantified in the soil, plant, and residue. This technique allowed us to determine the uptake of fertilizer N by rice, determine fertilizer use efficiency, and follow residual fertilizer N through various soil N pools. It will also allow us to quantify the uptake of N that was present in the rice straw that will become available for plant uptake through decomposition and net N mineralization in the following year.

Table 2 summarizes the fate of added fertilizer ^{15}N applied in May at the Maxwell site in the following fall and the spring (1998). The grain harvest removed 24% of the applied fertilizer ^{15}N and 10.8% of the added ^{15}N fertilizer remained in the above-ground straw. The loss of fertilizer amounted to 24% after 1 growing season and 54% after 1 year. The large loss of fertilizer shows the importance of volatilization and denitrification processes in controlling the fate of fertilizers in rice cropping systems. Some ^{15}N could have been leached or lost from the enclosed plot through horizontal flow, however other studies have shown that lateral fertilizer movement in rice paddies is minimal. On average, residual fertilizer N loss over the winter months was 41% mainly due to denitrification. In May 1998 just prior to planting, the incorporated straw treatments had more remaining fertilizer N than the burned treatments. Approximately 25% of the fertilizer N remaining in the surface straw in Fall 1997 was conserved in the incorporated treatments over the winter. This N from the surface straw was lost in the burned treatments. Additional microplots were installed in the incorporated treatments (flooded and non-flooded) at the Maxwell site in Oct. 1997 to examine the contribution ^{15}N fertilizer in the surface straw. In this second labeled N study, the aboveground ^{15}N-labelled residue was incorporated at an adjacent location where no ^{15}N-tracer fertilizer was applied the previous year . About 2% of the ^{15}N fertilizer originally applied was found in the surface straw in the following spring. Results from the microplots at Maxwell suggest that three-quarters of the N in the surface straw was lost over the winter in the incorporated plots. In Fall 1998, microcosms with rice straw, highly enriched with ^{15}N and ^{13}C, were installed in the incorporated and burned treatments at the Maxwell site to more clearly asses the impact of straw management practices on the N and C contribution of the straw residue to the subsequent rice crops.

Microbial biomass N represents a major sink for fertilizer N in rice. The microbial biomass contained 8.8% of the labeled fertilizer ^{15}N applied and 24% of the fertilizer ^{15}N remaining in the soil approximately 3 months after application at the Maxwell site (Fig. 4). One year after application the microbial biomass contained 4% of the original fertilizer applied (fert.) and 16.5 % of the fertilizer remaining in the soil (soil). The incorporated plots had more fertilizer N in the microbial biomass than the burned just after drainage in spring 1998. The soil organic fraction also represents a major sink for added fertilizer N in the soil at Maxwell. After 4 seasons of straw treatments, the incorporated treatments had more labile humic acids than the burned (data not shown); a major source of N for the crop plant. After one growing season winter-flooded labile humic acids had less fertilizer N than non-winter flooded plots (Fig. 5). This might explain the greater amounts of fertilizer N found in the flooded treatments during the growing season in 1997. Together, the soil organic fraction and the microbial biomass acted as a significant competitor with the rice plant for fertilizer N. At harvest after 1 growing season, 15% of the fertilizer N was in the SOM and microbial biomass while 37% was in the plant at the Maxwell site.

Table 2. Maxwell Site: Recovery of applied fertilizer ^{15}N as total N in soil (0-15 cm depth), Fall 1997 and Spring 1998. 2.4 g ^{15}N added per plot as urea 5/97.

Straw Treatment	Fall 1997 (pre-flood)		Spring 1998 (pre-plant)	
	^{15}N mg/plot	% of applied	^{15}N mg /plot	% of applied
BURN F	1.27	52.9	0.45	18.8
BURN NF	1.17	48.8	0.53	22.1
INCORP F	1.29	53.8	0.59	24.6
INCORP NF	1.31	54.6	0.57	23.8
Stats	NS		C ($p<0.09$)	
Soil N Mean	1.26	52.4	0.53	21.8
Grain Output	0.58	24.1	0.58	24.2
Loss[1]	0.56	23.5	1.29	54.0

[1] Loss includes soil ^{15}N below 15-cm sample depth.

Figure 4. Maxwell Site: ^{15}N recovery as microbial biomass N 1997-1998 (soil 0-15 cm depth). ^{15}N fertilizer applied in May 1997. Percentage values refer to percent of ^{15}N recovered either as percent of fertilizer applied (fert.) or that remaining in soil (soil).

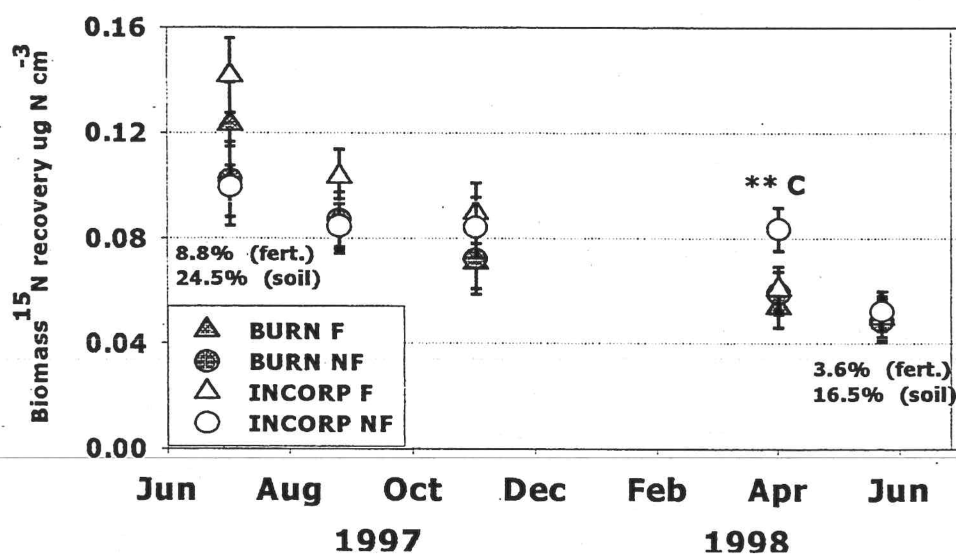
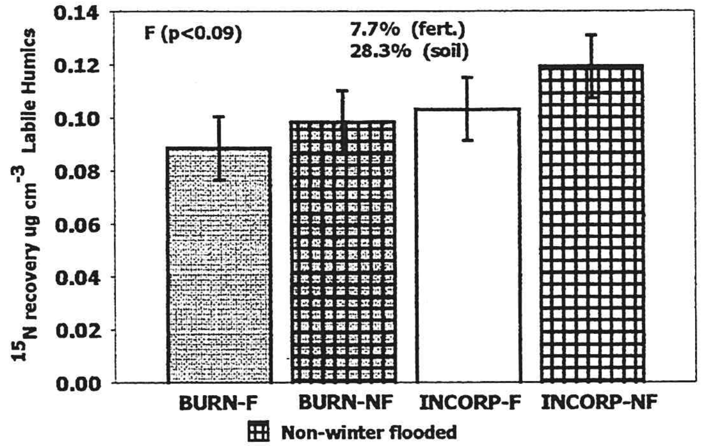


Figure 5. Maxwell Site: ^{15}N recovery as labile humic acid N 9/97 (soil 0-15 cm depth). ^{15}N fertilizer applied in May 1997. Percentage values refer to percent of ^{15}N recovered either as percent of fertilizer applied (fert.) or that remaining in soil (soil).



The Yuba site provided an opportunity to compare N use efficiency in a coarse textured rice soil to the clay-rich soils at the Maxwell and Biggs sites. Fertilizer N use efficiency was much lower at the Yuba site with only 14% of the added ^{15}N fertilizer ending up in the crop plant in Fall 1998 compared with 37% in the plant at the Maxwell site (Table 3). Recovery of fertilizer ^{15}N in the soil was 15% at harvest resulting in a loss of 71%. The loss at the Maxwell site was approximately 35% at harvest after 1 growing season. This large difference in fertilizer use efficiency and loss from the plant–soil system can be attributed to differences in soil and climatic factors between the two sites and years. The yield and N content of the Yuba site's rice crop was lower than that at Maxwell due to a shorter growing season in 1998 vs. 1997 and a less productive soil at the Yuba site (Table 4). Leaching at the Yuba site most likely played a larger role in the resulting higher fertilizer N loss rates due to very coarse soil texture found at Yuba compared to that found at Maxwell (Maxwell 51% clay vs. Yuba 23% clay). Further the contribution of lateral N loss at the Yuba site may have been more important since the soil is much higher in silt and plot borders were not installed at Yuba as they were at the Maxwell and Biggs sites. Although, as mentioned above, lateral fertilizer movement is normally minimal in rice systems with leaching and volatilization acting as the main soil loss pathways for fertilizer N, the high losses at the Yuba site may have been a exception to this rule.

Table 3. Yuba Site: Recovery of applied fertilizer ^{15}N as total N in soil (0-15 cm depth) at harvest 1998. 0.45 g ^{15}N added per meter as urea 5/97.

Component	^{15}N mg/plot	% of ^{15}N Applied
Soil (0-15 cm depth)	**6.7**	**15**
Plant total	**6.2**	**14**
Grain	3.7	8
Straw	2.5	6
Loss [1]	**31.8**	**71**

[1] Loss includes soil ^{15}N below 15 cm sample depth.

Table 4. Yuba Site: Rice yield and composition 9/98.

Component[1]	Yield	Carbon	Nitrogen	C/N
	kg ha^{-1}	g kg^{-1}		
Grain	**9452**	392	7.9	50
Straw	**6233**	344	5.4	64
Roots	**1509**	313	4.9	64

[1] grain yield expressed as 14% moisture content, straw and root yieldsexpressed as dry matter.

In 1998, the seasonal accumulation of above-ground biomass and total N was determined for rice from the microplots using labeled fertilizer N. The main objective was to determine the seasonal accumulation of biomass and N; and to assess when the residual fertilizer-N would becomes available and is accumulated by the crop. To increase the efficiency of residue-N or soil organic matter-N as a source of N for the subsequent crop, a close synchronization between the release of N from residue (net N mineralization) and the uptake of N by the rice crop would be advantageous. By following the total N uptake as well as the tracer N in the crop during the growing season, the timing of net N release from residue or soil organic matter can be determined and the effects of straw management can be assessed.

The accumulation of biomass during the growing season was unaffected by winter flooding and rice straw burning (Fig. 5). The highest rate of biomass accumulation occurred during the month of July and in early August. Because rice was seeded later as usual due to the wet conditions in the spring, there was still a strong increase in total biomass in August. In contrast to total biomass accumulation, total N accumulation occurred earlier. This is a usual phenomenon and most crops accumulate most of their N before they reach maximum growth. The maximum amount of total N occurred toward the end of July and declined thereafter (Fig. 6). The intensity in the decline in total N appears to have been dependent on rice residue management practices as the strongest decline was observed for the residue incorporated and winter flooded treatment. Although such a sharp decline in total N following the early August sampling for the residue incorporated and winter-flooded treatment might have been an anomaly, a decline in total N in a crop often occurs once the reproductive stage has been reached and grain fill occurs. Volatilization losses occur through the leaves when the N from vegetative plant components is converted into a soluble form and translocated into the seeds.

Figure 5: Maxwell Site: Total plant biomass (roots and shoots) over growing season, 1998.

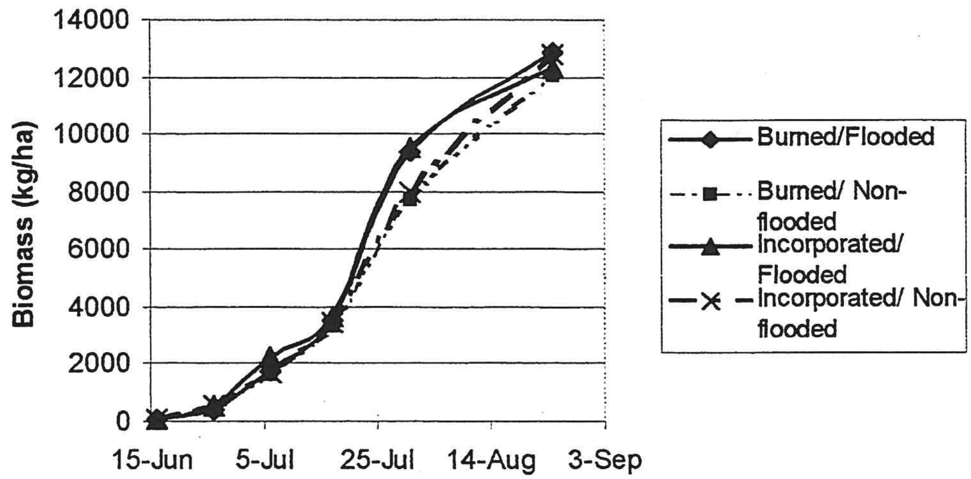
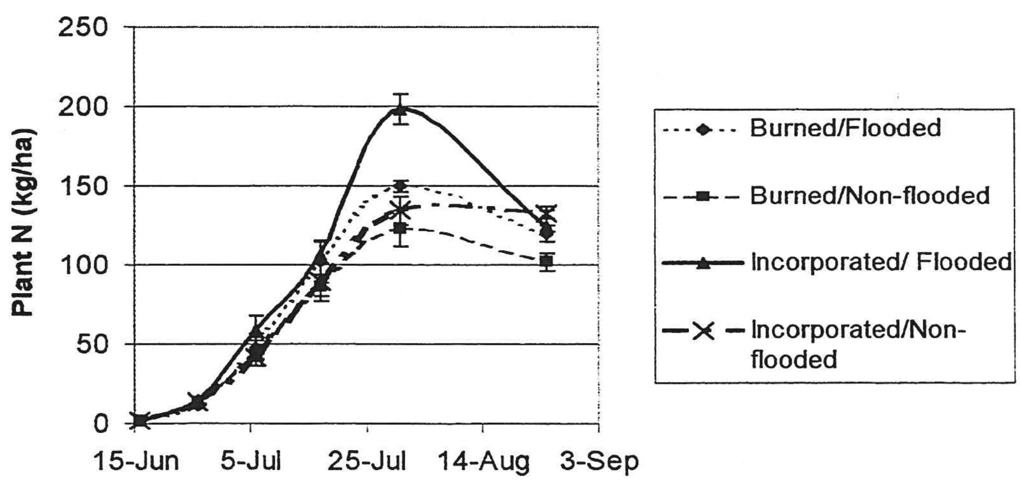


Figure 6: Maxwell Site: Total plant N (roots and shoots) over growing season, 1998.



At the Maxwell site the amount of residual soil fertilizer N that was recovered by the second rice crop was followed throughout the growing season in 1998. To separate the amount of tracer N that was accumulated by the crop from above-ground residue and from below-ground sources (roots, soil organic matter, microbial biomass), two concurrent ^{15}N-tracer residue studies were carried out as mentioned previously in the incorporated treatments. One of the tracer-N studies consisted of two sources of ^{15}N: below ground plus the aboveground residue (original microplots established in 1997). In the second tracer study, the aboveground ^{15}N-labeled residue was incorporated at an adjacent location where no ^{15}N-tracer fertilizer was applied the previous year (additional microplots established in Fall 1997). In the first residue tracer study, all the ^{15}N that was traced in the 1998 rice crop was derived from below and above-ground ^{15}N labeled sources from 1997. In the second tracer study all of the ^{15}N in the rice crop was derived from above-ground sources from 1997, i.e., residue. It should be pointed out that most if not all of the tracer N that was accumulated by the second year rice crop (1998) was fertilizer N that was used by the first year rice crop or been utilized by soil microorganisms, followed by net mineralization. Therefore, a residual fertilizer-N effect, defined as the amount of fertilizer-N that is accumulated by the second crop, is in fact always an indirect, residual effect as in the year of application.

As somewhat expected, the highest below-ground residual fertilizer effect was found for the incorporated /winter flooded treatment, the lowest for the burned treatments (Fig. 7). Incorporating large amounts of residues with a high C:N ratio will lead to immobilization and protect inorganic N from being lost through leaching, volatilization and denitrification. Adding rice straw residues would lead to increased immobilization, lower losses and hence increase the N pool that can contribute N to the subsequent rice crop. The above-ground contribution of N to the subsequent rice crop never exceeded 1.5 kg N ha^{-1} (Fig. 8). The amount of fertilizer-N applied in 1997 and accumulated in the 1998 rice crop was small as the majority of the fertilizer N in the residue-N was derived from existing unlabeled soil organic matter N. Therefore, it is clear from both the plant uptake and residual soil N data that the below-ground contribution of residual fertilizer-N to the subsequent rice crop is much more important than the amount of fertilizer-N from above-ground sources (surface straw). Winter flooding may have promoted the contribution of above-ground residue-N in the early stage of the growing season. Toward the end of the growing season, however, the crop that was grown in the soil that was not winter flooded showed a slightly higher ^{15}N contribution.

Figure 7: Maxwell Site: Residual fertilizer uptake by plants through below-ground pools. Graph shows amount of 1997 applied fertilizer that entered 1998 plants via soil N pools. Does not include fertilizer N through 1997 residue.

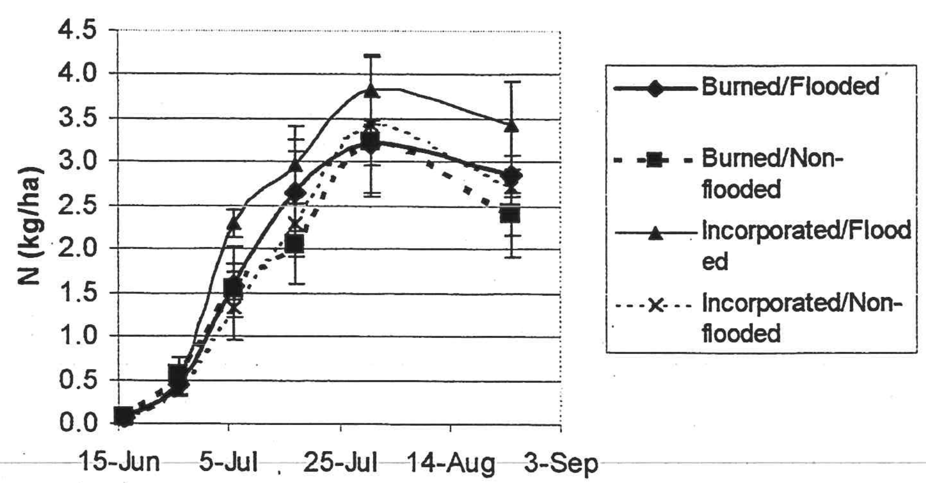
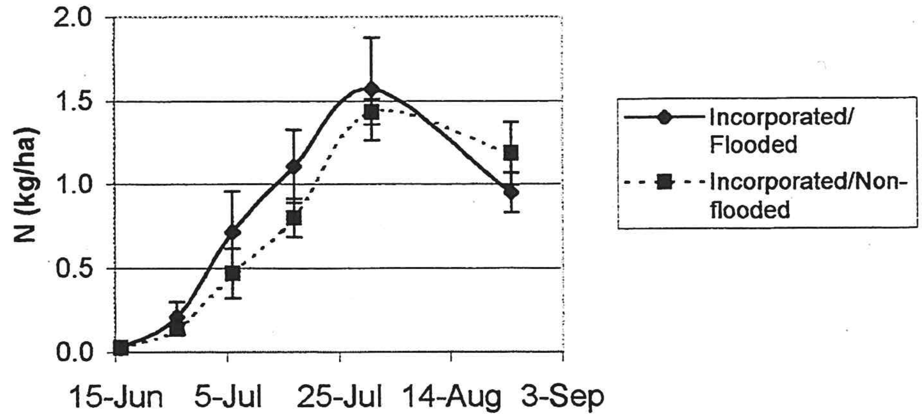


Figure 8: Maxwell Site: Total plant N from residue 1998. Applied residue contained an average of 20 kg N/ha, with up to 1.5 kg N/ha in the following year's crop (7.5%).



The grain yield at Maxwell was between 9 and 10 tones ha^{-1} and residue management practices had no significant effect on yield (Fig. 9). Straw yield was slightly less and again straw management practices did not seem to have an effect. Grain yields were lower at the Biggs site but were not affected by rice straw management practices (Fig. 11). Across both sites, yields are slightly lower than in 1997 which is likely due to late seeding caused by the wet conditions in May and early June. It appears that after 5 years of alternative rice straw management practices, there has been no adverse effect of straw management on yield. Although incorporating rice straw may lead to an increase is weeds and pest occurrence, its impact on grain yield did not manifest itself. Whether there is a gradual increase in the occurrence of pests due to residue incorporation may only become apparent after a more prolonged period of time.

At the Maxwell site when no fertilizer-N was applied, there was a clear increase in grain yield for those treatments when straw was not removed from the field (rolled and incorporated) (Fig. 10). This strongly indicates that above-ground residue acted as a source of N for rice. Although the yearly N-contribution from residues may be small, the cumulative effect of five years of incorporating the residue had a clear impact on the N supply power of the soil leading to higher grain yield. The absence of any residue-N response in the fertilized field is likely due to the fertilizer recommendations that are still based on residue burning. All the fields received sufficient or more than sufficient N fertilizer and any possible contribution of N from residue would be masked as yield had already reached a maximum.

Such a strong grain yield response due to residue incorporation did not manifest itself at the Biggs site (Fig. 12). Although baling in combination to flooding lead to the lowest grain yield, fields that were burned showed comparable or higher seed yield than in those fields were the straw was incorporated. One major difference between the two sites is that the background N supply power of the soil appears to be higher at Biggs than at Maxwell as non-fertilized rice almost reached a similar yield than fertilized rice (Figs. 11 and 12). When the straw was burned and the field winter flooded, a grain yield of 7000 $kgha^{-1}$ was obtained which was slightly less than the seed yield of the similar residue treatment but with the application of N fertilizer. As the baled, unfertilized, and non-winter flooded treatment showed the lowest seed yield (Fig. 12), other nutrients that N might have controlled final seed yield at Biggs. As the soil at Biggs shows low available K levels, this nutrient might have become more critical than N. However, no clear explanation for the discrepancy between the two sites on the effect of residue incorporation on grain yield is yet available.

To determine how alternative straw management practices would effect N availability, an N fertilizer rate trial was conducted at Maxwell. Nitrogen fertilizer rates varied between 0 and 160 kg N ha^{-1}, located in winter flooded and non-winter flooded plots where the residue was burned or incorporated. When no fertilizer was applied, residue incorporation almost doubled the grain yield compared to the yield when residue was burned (Fig. 13). A similar grain yield was obtained when the residue was burned and 30 kg N ha^{-1} of fertilizer was applied compared to the yield when the residue was incorporated and no fertilizer was applied. Hence, the overall N effect of residue incorporation was equivalent to 30 kg N ha^{-1}. This is an important initial figure because this information can be used to readjust fertilizer-N recommendation when farmers are incorporating rice straw residues. However, the 30 kg N ha^{-1} is based on one year's data from only from one site and from a study that was conducted in a year which had an unusual growing season. Therefore, some caution is warranted with the interpretation and extrapolation of this N fertilizer equivalent value.

Figure 9: Maxwell Site: Main plot harvest yield 1998. Yield calculated based on 0.5 m^2 quadrats.

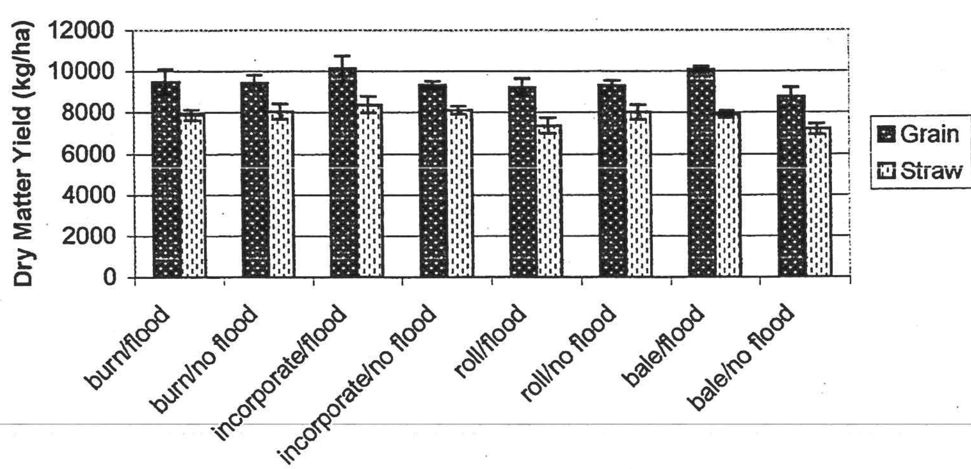


Figure 10: Maxwell Site: Zero N plot harvest yield 1998. Yield calculated based on 0.5 m^2 quadrats.

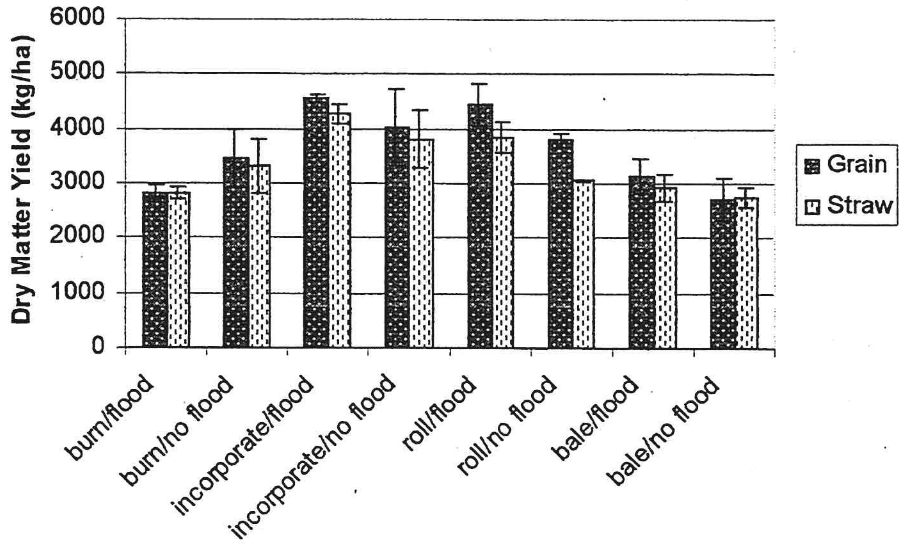


Figure 11: Biggs Site: Main plot harvest yield 1998. Yield calculated based on 0.5 m^2 quadrats.

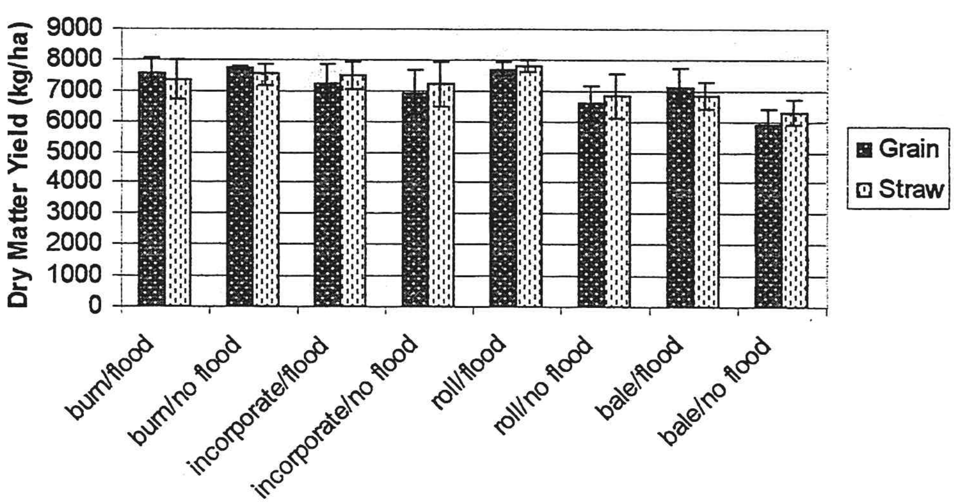


Figure 12: Biggs Site: Zero N plot harvest yield 1998. Yield calculated based on 0.5 m^2 quadrats.

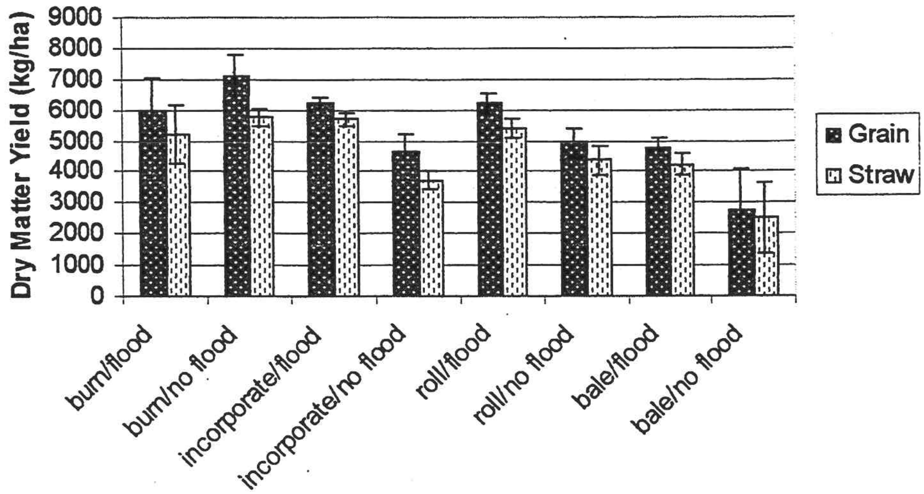
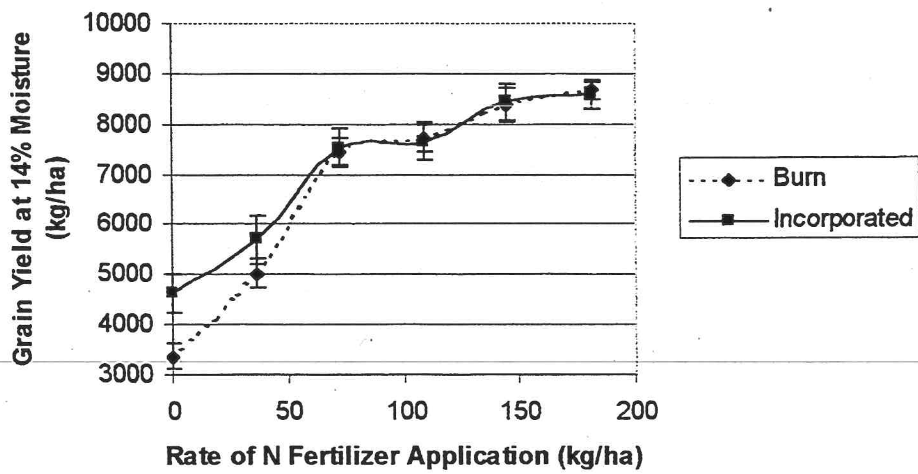


Figure 13: Maxwell Site: Yield for different rates of N application 1998. Error bars are standard error of eight replicates, flood treatments combined.



PUBLICATIONS OR REPORTS 1998:

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CONCISE GENERAL SUMMARY OF CURRENT YEARS RESULTS:

Alternative rice straw management practices affected the availability of added nutrients, i.e., fertilizer-N but did not show an effect on grain yield. The availability of soil N was increased by winter flooding at both the Biggs and Maxwell sites. The increase in available N during the spring probably resulted from the greater decomposition of the prior years rice residue with winter flooding. Winter flooding has consistently been found to increase rice straw residue decomposition compared to winter fallow without winter flooding at both straw management trial sites. Winter flooding also produced greater available inorganic N at the Maxwell site during the growing season in 1997 and 1998 (preliminary data not shown). Unfortunately, the available soil N in the spring was most likely lost through denitrification processes following flooding and seeding and was not available for plant uptake. In the fall, the straw incorporated plots showed a tendency to immobilize added fertilizer N at the Maxwell site. This is confirmed by higher amounts of fertilizer found in the microbial biomass in the incorporated plots. The immobilization of N would increase sustainable N cycling by preventing soil N loss through denitrification during the wet winter months. Overall, straw incorporation tended to have positive effects on the N status of the soil.

We studied the fate of fertilizer N by using a heavy isotope of N (^{15}N) that can be traced to the plant, microbial biomass, and other soil pools. The uptake of ^{15}N labeled fertilizer provides information on fertilizer nitrogen recommendations and plant nitrogen use efficiency under the different flood and residue treatments. We found that only about one third of the fertilizer N was taken up by the rice crop at Maxwell in 1997 and 15% at the Yuba site in 1998. This large difference in fertilizer use efficiency and loss from the plant–soil system can be attributed to differences in soil and climatic factors between the two sites and years. The generally low fertilizer N use efficiency found at both sites shows the importance of soil N in supplying N for rice crop uptake. A significant portion of the fertilizer N was found in the microbial biomass and soil organic matter late in fall and following spring at the Maxwell site. This shows that the microbial biomass was a strong competitor for the fertilizer N. It also exemplifies the importance of the microbial biomass and soil organic matter in controlling the fate of soil. The activity of the microbial biomass controls the rate at which soil N will become available for rice crop uptake. The majority of the N taken up by the rice was soil N and shows the dependency of the rice on the mineralization activity of the microbial biomass. The results also showed that a significant amount of fertilizer was apparently lost through volatilization, denitrification activity and leaching. Fertilizer N recovered after 1 year as total soil N (pre-plant 1998) was found to be greater with straw incorporation at the Maxwell site compared with the burned residue treatments. The lower conservation of N with straw burning can be attributed to the N lost in the surface straw due to fall burning. While this difference in N conservation represents only about 2% of added fertilizer N per year, the cumulative effect of incorporating rice straw is much higher and was equivalent to 30 kg fertilizer N ha^{-1}. The additional N availability has resulted from a substantially larger soil organic N pool in rice soils that receive annual straw inputs. A larger potentially available soil N pool is of even greater importance in rice systems due to rice's heavy reliance on N derived from the soil (50-85%) compared to fertilizer N.

In 1998, the seasonal accumulation of above-ground biomass and total N was determined for rice from the microplots using labeled fertilizer N. The main objective was to determine the seasonal accumulation of biomass and N; and to assess when the residual fertilizer-N would becomes available and is accumulated by the crop. To separate the amount of tracer N that was accumulated by the crop from above-ground residue or from below-ground sources (roots, soil organic matter, microbial biomass), two concurrent ^{15}N-tracer residue studies were carried out as mentioned previously in the incorporated treatments. One of the tracer-N studies consisted of two sources of ^{15}N: below ground plus the aboveground residue (original microplots established in 1997). In the second tracer study, the aboveground ^{15}N-labeled residue was incorporated at an adjacent location where no ^{15}N-tracer fertilizer was applied the previous year (additional microplots established in Fall 1997). As somewhat expected, the highest residual fertilizer effect was found for the incorporated /winter flooded treatment, the lowest for the burned treatments. Incorporating large amounts of residues with a high C:N ratio will lead to immobilization and protect inorganic N from being lost through leaching, volatilization and denitrification. The above-ground contribution of N to the subsequent rice crop never exceeded 1.5 kg N ha^{-1}. The amount of fertilizer-N applied in 1997 and accumulated in the 1998 rice crop was small as the majority of the fertilizer N in the residue-N was derived from existing unlabeled soil organic matter N. Therefore, it is clear from both the plant uptake and residual soil N data that the below-ground contribution of residual fertilizer-N to the subsequent rice crop is much more important than the amount of fertilizer-N from above-ground sources (surface straw). No significant effect of winter flooding was seen on plant N uptake in 1998, however, winter flooded treatments tended to have higher amounts of N during the growing season. This trend in plant N uptake of fertilizer N matches the trend of greater available soil inorganic fertilizer N in the winter-flooded treatments as compared to the non-flooded found throughout the year.

The grain yield at Maxwell was between 9 and 10 t ha^{-1} and residue management practices had no significant effect on yield. Straw yield was slightly less and again straw management practices did not seem to have an effect. Grain yields were lower at the Biggs site but were not affected by rice straw management practices. Across both sites, yields are slightly lower than in 1997 which is likely due to late seeding caused by the wet conditions in May and early June. It appears that after 5 years of alternative rice straw management practices, there has been no adverse effect of straw management on yield. Although incorporating rice straw may lead to an increase is weeds and pest occurrence, its impact on grain yield did not manifest itself. Whether there is a gradual increase in the occurrence of pests due to residue incorporation may only become apparent after a more prolonged period of time.

At the Maxwell and Biggs sites, a zero-N fertilization trial was conducted to assess the N supply power of the soil as affected by the difference straw management practices. At Maxwell, the incorporation of rice straw showed a strong positive response to grain yield, clearly suggesting that straw incorporating leads to a higher N supplying power. Grain yield could increase to up to close to 50 % when rice straw was incorporated. At the Biggs site, however, a different picture emerged and straw incorporation did not lead to higher yield when no N fertilizer was applied. At present time, we have no explanation for this discrepancy in the results between the two sites.

Rice residue contains N and can serve as a source of N for the subsequent rice crop. The impact of incorporating rice residue on N availability and yield was assessed at the Maxwell site. An N fertilizer rate trial was conducted when rice straw had been removed or incorporated for 5 years. When no fertilizer was applied, residue incorporation grain yield increased to 4000 kg ha^{-1} from 2800 kg ha^{-1} when residue was burned. When the residue was burned and 30 kg N ha^{-1} fertilizer was applied, the yield became comparable when residue was incorporated and no fertilizer was applied. Hence, the overall N effect of residue incorporation was equivalent to 30 kg N ha^{-1} of fertilizer. This is an important preliminary figure as this information will be used to readjust fertilizer-N recommendation when farmers are incorporating rice straw residues.

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