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NITROGEN IMMOBILIZATION BY RICE STRAW INCORPORATED IN LOWLAND RICE PRODUCTION

by W. A. WILLIAMS, D. S. MIKKELSEN, K. E. MUELLER*, and J. E. RUCKMAN

Department of Agronomy, University of California, Davis

INTRODUCTION

We have reported previously on the usefulness and management of high-nitrogen organic materials – leguminous green manures – in rice production [8 9]; the evidence shows that vetch containing 3 to 4 per cent nitrogen is a highly effective and inexpensive source of nitrogen, if properly incorporated and the soil promptly flooded.

However, the management of low-nitrogen organic materials such as rice straw is of even greater interest because every rice crop produces residues requiring disposal prior to the planting of the next crop. The nitrogen concentration in rice straw is usually between 0.4 and 0.7 per cent dry basis. If the incorporation of this straw is followed by a non-flooded crop, we will expect that the amount of inorganic nitrogen in the soil available to plants will be decreased by the strong competition for nitrogen by a wide variety of micro-organisms [4]. In aerobic soils fresh organic materials containing less than approximately 1.5 per cent nitrogen generally immobilize much of the soil nitrogen otherwise available to crop plants during the growing season following incorporation [3].

Acharya [1] studied the decomposition of rice straw under aerobic and also anaerobic conditions in laboratory experiments, and he found that the nitrogen immobilized by rice straw decomposing under aerobic conditions was about six times that immobilized under anaerobic conditions. Guha Sircar et al.[5] presented similar evidence and reported that a nitrogen concentration of 1.7 to 1.9 per cent was necessary to avoid immobilization of nitrogen under aerobic conditions, while 0.45 to 0.50 per cent nitrogen was sufficient under anaerobic conditions. Decomposition of crop residues in an anaerobic environment is much slower than aerobic decomposition because

* Present address: The Ford Foundation, Lahore, Pakistan.

of a different soil microflora involved, essentially a bacterial microflora that does not require oxygen for respiration. Bacterial degradation of large quantities of substrate must take place to allow assimilation of small amounts of carbon, hence the demand for nitrogen for protoplasmic synthesis is less than under aerobic conditions [1].

The published reports on this problem are very scarce, and field response data are most deficient. Two recent reviews [2 7] of the subject reflect a lack of information on crop responses to the anaerobic decomposition of crop residues in field environments. Thus, the purpose of the present investigation was to study the availability of nitrogen from rice straw to lowland-grown rice, as affected by the nitrogen concentration of the straw and by nitrogen added in other substances. The net nitrogen immobilization percentage was ascertained for rice straw decomposing in flooded paddy soils based on rice crop response and nitrogen recovery data. Straws containing less than the net nitrogen immobilization percentage depressed yield, and straws having a greater nitrogen concentration enhanced yield of rice.

METHODS

The experiments were performed at the Rice Experiment Station, Biggs, California on Stockton clay soil which is typical of those used for rice production in the Central Valley of California and is described in a previous report [6]. The procedure was to remove the soil to a depth of 4 inches from all plots including the control plots, emplace treatment materials in a uniform layer, and then replace the soil in a uniform manner. Each plot was 8 × 8 ft, and a 4 × 4 ft quadrat in the center was used for yield measurements on the rice crop. Randomized block designs were used in the experiments. All treatments except the controls were replicated three times; the controls were replicated at least six times. The land was not cropped in the growing season prior to an experiment. Previous work indicates that nitrogen is the only element that produces significant yield responses in rice at the experiment sites.

Experiment 1

The treatments consisted of applications of rice straw, varying in amount and in nitrogen content, with or without woollypod vetch hay (*Vicia dasycarpa* Ten.), in factorial combinations and with appropriate controls. Two lots of rice straw containing 0.45 and 0.55% nitrogen on a dry basis, respectively, were applied at rates of 4,000 or 8,000 lb/acre (dry) after being ground to pass through a 1/2-inch screen. The straw was collected in March

1962 after having overwintered in the field. The vetch was harvested April 26, 1962 at the bloom stage and contained 3.87% nitrogen (dry basis). The amount of vetch applied was adjusted in the vetch and straw-vetch treatments so that the total amount of nitrogen contained was equivalent to 60 lb/acre. The treatments were applied on April 30. The next day rice (*Oryza sativa, japonica* var. Caloro) was seeded at 150 lb/acre, and the plots were flooded and maintained continuously under a water depth of 6 inches. The crop was harvested on October 19, 1962.

Experiment 2

The treatments consisted of varying amounts of fresh purple vetch tops (*Vicia benghalensis* L.) applied with or without rice straw. The straw was collected in November 1962 a short while after harvest. It contained 0.64% nitrogen on a dry basis and was applied at the rate of 6,000 lb/acre (dry) after grinding. The vetch, which was cut on May 16, 1963 in the early bloom stage, contained 3.39% nitrogen (dry basis). It was applied at rates equivalent to 30, 60, 90, 120, or 150 lb N/acre. The treatments were applied on May 17. The next day rice (var. Calrose) was seeded at 150 lb/acre and the plots flooded. The crop was harvested on October 10, 1963.

Experiment 3

The treatments consisted of applications of rice straw, varying in nitrogen content, plus various rates of urea, in factorial combinations and with appropriate controls. Two lots of straw containing 0.45 and 0.70% nitrogen (dry basis), respectively, were applied at the rate of 6,000 lb/acre (dry). The low-nitrogen straw was collected in December 1963; the high-nitrogen straw was collected in February 1964 from a different field after some winter weathering had occurred. Urea was applied at rates equivalent to 15, 30, 60, or 120 lb/acre in dry form to no-straw plots, and in water solution sprayed on the straw after grinding, but prior to placement, in the excavated plots. The treatments were applied on April 30. The next day rice (var. Caloro) was seeded at 150 lb/acre and water applied. The crop was harvested October 14, 1964.

RESULTS

Experiment 1 – Straw containing 0.46 or 0.55% nitrogen and straw-vetch combinations totaling 60 lb/acre in nitrogen content

The 0.46%-N straw caused a depression in grain yield in the absence of vetch (Table 1). The 0.55%-N straw had no significant effect. Differences due to the rate of straw applied were not significant.

Vetch alone equivalent to 60 lb N/acre nearly doubled the yield of grain relative to the control treatment. All plots containing straw-vetch combinations were significantly lower yielding than the vetch-alone treatment, but they also were higher yielding than the control. The high rate of straw in combination with vetch reduced yield more than did the low rate of straw with vetch.

TABLE 1

Effect of rice straw and vetch applications on rice grain and straw production and on their recovery of nitrogen from these materials (experiment 1)

Materials applied and nitrogen content (lb/acre)	Grain		Straw		Nitrogen recovery	
	Yield** cwt/acre	N %	Yield cwt/acre	N %	lb/acre	%
Control	32	1.04	29	0.56	—	—
0.46%-*N straw*						
2 tons/acre (18N)	26	1.17	22	.60	−5	−28
4 tons/acre (37N)	28	1.05	30	.55	−3	− 8
0.55%-*N straw*						
2 tons/acre (22N)	30	1.02	28	.51	−4	−18
4 tons/acre (44N)	33	1.03	30	.56	1	2
0.46%-*N straw*						
2 tons/acre + vetch (60N)*	48	1.04	40	.54	20	33
4 tons/acre + vetch (60N)*	38	1.04	35	.53	8	13
0.55%-*N straw*						
2 tons/acre + vetch (60N)*	49	1.00	53	.48	23	39
4 tons/acre + vetch (60N)*	43	0.98	40	.46	10	17
Vetch, 0.81 T/acre (60N)	63	1.02	61	.54	43	72
LSD 5%	10	N.S.	10	N.S.		

* Enough vetch (3.87% N) added to raise the total nitrogen content of the combination to 60 lb/acre.

** Grain yield on a 14% moisture basis. All other data are on a dry-weight basis.

The grain and straw components of the rice were analyzed for total nitrogen, and the nitrogen content of the combined components (tops) from the control treatment was substracted from the nitrogen content of tops from each organic matter treatment. These nitrogen increments are considered to approximate the amount of nitrogen obtained by the crop from the applied materials, and are expressed also as the percentage of nitrogen recovered by the crop from the applied organic matter (straw and/or vetch).

Both straws (0.46 and 0.55% N) applied at the rate of 2 tons/acre gave negative recovery percentages, indicating nitrogen 'tie-up' (Table 1). The two straw treatments at 4 tons/acre had no marked effect on nitrogen recovery, but the straw-vetch combination treatments resulted in nitrogen release from the added organic materials and subsequent absorption by the rice plants. Treatments with both straws and vetch added caused recoveries greater at the 2 tons/acre level of straw than at the 4 tons/acre level of straw; this result was associated with the greater amount of vetch contained in the two low straw rate plus vetch treatments. Nitrogen recovery was greatest of all treatments (72 per cent of the applied nitrogen) in the vetch-only treatment.

It is evident from the results of this experiment that the nitrogen fertility effect of low-nitrogen materials is much different in a flooded rice paddy than in an aerated soil growing an upland crop. The essentially neutral effect of the 0.55% N straw only treatments on rice grain yield contrasts sharply with the effect of barley green manure, with a much higher nitrogen concentration (1.17%), on sugar beet growth [10]. Following incorporation of the barley green manure sugar beet seedling weight was reduced to 25 per cent of that of the control (no fertilizer), with a closely associated decrease in nitrate-nitrogen concentration. Results of the first experiment revealed that the net nitrogen immobilization percentage for materials incorporated in a flooded rice field must be much lower than the generally accepted average of 1.5 per cent [3] for materials incorporated in soils providing an aerobic environment for decomposition. Subsequent experiments were conducted to elucidate further the relationship between straw nitrogen and rice crop response using a wider range of straw-nitrogen contents, with supplemental nitrogen added in the organic high-nitrogen source, vetch, in experiment 2 and in an inorganic form, urea, in experiment 3.

Experiment 2 – Straw containing 0.64% nitrogen with various amounts of fresh vetch

The yield of grain following the straw-only treatment was 9 cwt/acre higher than that of the control (a difference significant at the 5% level based on a 't' test for those two treatments). Plots treated with straw plus 30 lb N/acre, supplied in vetch, achieved a peak rice yield of 68 cwt/acre. Vetch-alone treatments resulted in a peak yield of 70 cwt/acre at 90 lb N/acre (Fig. 1). Eye-fitted curves of the yield responses to straw and no-straw treatments as a function of supplemental nitrogen supplied by vetch are similar convex curves. Excessive nitrogen caused decreases from maximum yield by delaying maturity. The main effect of the straw was to displace the yield response curve to the left, indicating a benefit from the nitrogen supplied by the straw approximately equal to the straw's nitrogen content.

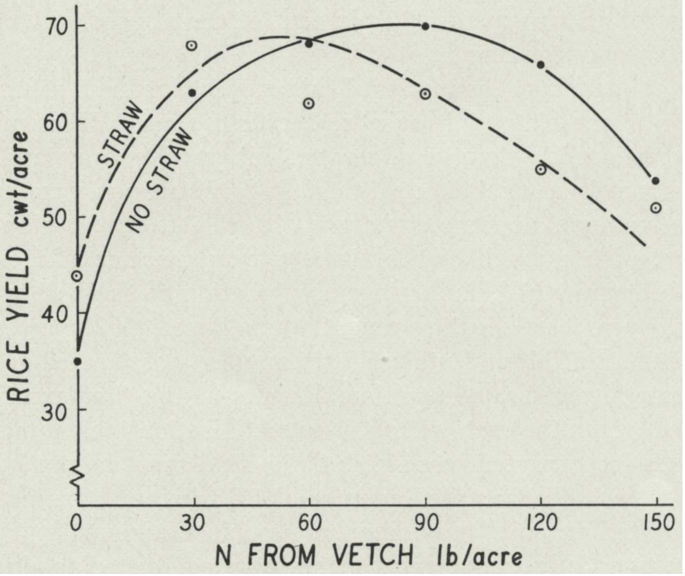

Fig. 1. The effect of vetch and rice straw applications on the yield of rice grain (experiment 2). The curves were fitted by eye.

Analytical data were used to estimate nitrogen recovery in rice tops, as in experiment 1. For the lowest rate of vetch applied (30 lb N/acre) recovery of vetch-supplied nitrogen was 103 per cent (Table 2). Although absolute recoveries generally increased with higher levels of vetch, percentage recoveries dropped to a minimum of about 50% at the highest levels of vetch. The percentage nitrogen recoveries from vetch-straw treatments were substantially lower than the corresponding vetch-only treatments.

Recovery of nitrogen supplied by straw alone amounted to 26%. Thus, in this experiment, an increase both in yield of grain and in recovery of nitrogen from the straw resulted from the straw-only treatment. These responses are associated with the higher nitrogen

TABLE 2

Effect of vetch and rice straw applications on rice grain and straw production and on their recovery of nitrogen from these materials (experiment 2)

Materials applied and nitrogen content (lb/acre)	Grain		Straw		Nitrogen recovery	
	Yield* cwt/acre	N %	Yield cwt/acre	N %	lb/acre	%
No treatment control	35	1.00	30	0.47	–	–
Vetch (30N)	63	.93	52	.48	31	103
Vetch (60N)	68	.99	57	.52	43	72
Vetch (90N)	70	1.01	62	.63	56	62
Vetch (120N)	66	1.13	59	.66	59	49
Vetch (150N)	54	1.30	76	.77	75	50
Straw (38N) control	44	.98	37	.47	10	26
Straw (38N) + Vetch (30N)	68	.95	60	.46	39	57
Straw (38N) + Vetch (60N)	62	1.10	59	.56	48	49
Straw (38N) + Vetch (90N)	63	1.09	65	.61	54	42
Straw (38N) + Vetch (120N)	55	1.28	61	.76	63	40
Straw (38N) + Vetch (150N)	51	1.33	67	.78	66	35
LSD 5%	16	.08	15	.12		

* Grain yield on a 14% moisture basis. All other data are on a dry weight basis.

concentration (0.64%) relative to that of the straw lots in experiment 1 (0.46 and 0.55% N).

Experiment 3 – Straw containing 0.45 and 0.70% nitrogen and treated with urea equivalent to amounts of nitrogen from 15 to 120 lb/acre

Without urea, the 0.70%-N straw application increased grain yield 7 cwt/acre while the 0.45%-N straw decreased yield 5 cwt/acre (LSD 5% = 5) relative to the control treatment (Fig. 2). The peak yield with both types of straw occurred where supplemented by 60 lb N/acre from urea sprayed on the straw. No difference in yield of grain resulted from the difference in nitrogen concentration of the straws when the optimum amount of supplemental nitrogen from urea was added. The highest yields from urea alone were obtained with 30 and 60 lb N/acre, but this maximum response was lower than either peak yield with straw–urea combinations. This response to urea sprayed on rice straw is in sharp contrast to the results of Broadbent and Nakashima [4] using urea and barley straw (0.53% N) in an aerobic soil environment. They found that the decomposing straw in well-aerated pots immobilized substantial amounts of the

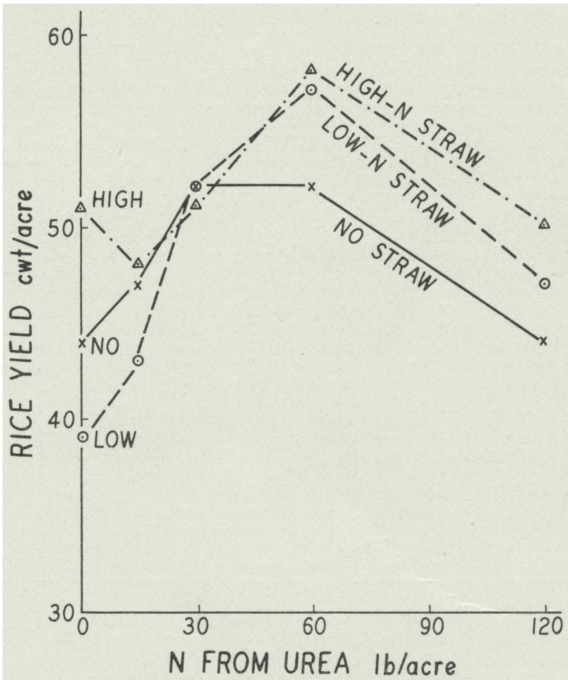

Fig. 2. The effect of rice straw nitrogen content and level of nitrogen from urea on the yield of rice grain (experiment 3).

added urea. Even when the urea-treated straw was preincubated for extended periods, they observed that the recovery of urea-nitrogen by sudangrass was invariably lower where the barley straw had been added. However, in this experiment not only was there an absence of a depressing effect on the response to urea, but the straws appeared to supplement the urea response.

DISCUSSION

In these field experiments, the rice yield response resulting from the incorporation of rice straw is a function of the nitrogen concentration in the straw (Fig. 3). The magnitude of response varies among the experiments, but in every case positive yield responses occur well below 1 per cent nitrogen in the straw and in the straw-supplemental nitrogen combinations. Bartholomew [2] has stated, in his recent review of immobilization of nitrogen by plant and

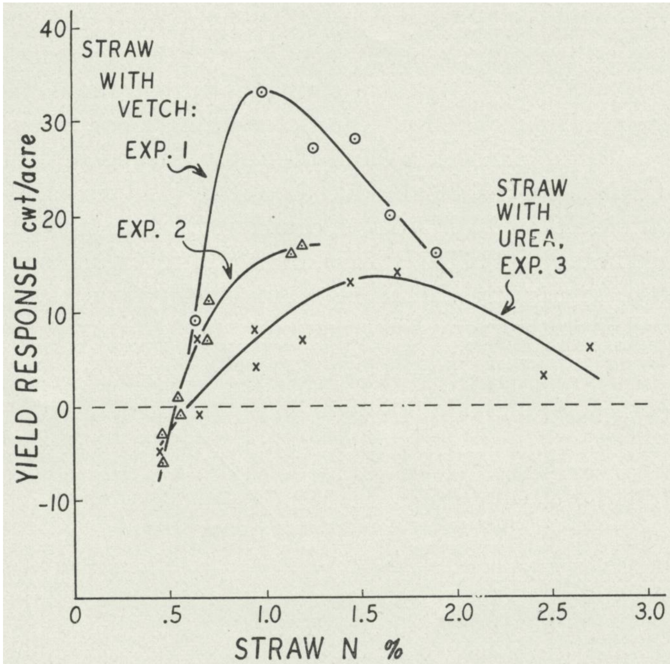

Fig. 3. The yield response of rice as related to the nitrogen content of straw and straw plus supplemental nitrogen combinations. The curves were fitted by eye.

animal residues, that from 1 to 2 per cent nitrogen is needed to satisfy the agents of decomposition. This considerable range of values in the amount of nitrogen needed for decomposition results from variation in the nature of the organic constituents of the material, soil temperature, soil pH, soil moisture, the amount of available nitrogen and other nutrients in the soil, and the position of the material in the soil [2 7]. We may add now that flooding the soil causes a marked decrease in the lower limit of the nitrogen needed in the decomposition of crop residues in the field.

Net nitrogen immobilization percentage in rice straw incorporated in flooded rice fields

It is possible to make seven comparisons between various lots and amounts of rice straw and their no-straw control treatments in the absence of supplemental nitrogen, in the above experiments.

When these rice yield responses are plotted thus against the nitrogen percentage of the straw, a highly significant linear regression results (Fig. 4), $Y = 57.6N - 31.4$. It is clear that nitrogen immobilization and mineralization, as reflected in rice yield response, is associated directly with the nitrogen level in the straw. Straws with nitrogen concentrations above 0.6% produced positive yield responses, while those with less than 0.5% nitrogen caused reductions in yield. When evaluated in terms of field response, the net nitrogen immobilization percentage in rice straw (percent of original dry material) can be calculated from the regression equation to be 0.54 per cent.

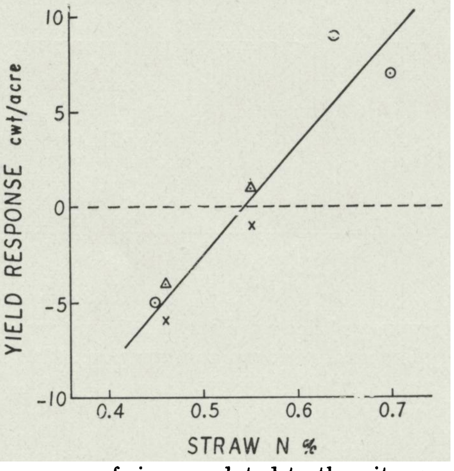

Fig. 4. The yield response of rice as related to the nitrogen content of straw applied, without supplemental nitrogen. The linear regression is highly significant; the net nitrogen immobilization percentage is 0.54%. (The cross, circle, and triangle represent 2, 3, and 4 T straw/acre, respectively.)

The goodness of fit of the regression line ($p < 1\%$) confirms the importance of the nitrogen percentage in the straw. The effect of other confounding variables, such as the amount of straw (2 to 4 tons/acre) and length of exposure to weathering (1 to 6 months of the rainy season), was insignificant.

Our conclusion is that the nitrogen requirement for the decomposition of rice straw in flooded soils is one-third the average concentration of nitrogen required for organic residue decomposition in an aerobic soil environment (0.54 *vs* 1.5 per cent). Practically, this means that rice crop residues produced at moderately high nitrogen fertility conditions will not immobilize nitrogen, but rather will release nitrogen during decomposition in a flooded soil environment. This fact has considerable agronomic significance, and it is evident that a reassessment of procedures for managing crop residues in the production of crops under flooded conditions is in order. Abundant rice crop residues from continually advancing yields with improving technology need no longer be viewed with aversion from the aspect of nitrogen fertility. However, it is apparent that methods and machinery for proper incorporation need renewed investigation.

SUMMARY

The nitrogen supplying power of rice straw for flooded rice production was studied in three field experiments. The net nitrogen immobilization was observed to be 0.54 per cent of the original dry weight of the straw as determined by grain yield responses over single growing seasons. Straws with higher nitrogen concentrations increased grain yield on nitrogen deficient soil, and straws with lower nitrogen concentrations depressed yield.

Supplemental nitrogen applied in either urea or vetch resulted in yield increases in the presence of both high and low nitrogen straws. No significant immobilization of supplemental nitrogen was found to result from straw applications.

The net nitrogen immobilization percentage obtained in these experiments is approximately one-third the average of values obtained by other workers. We infer that the anaerobic environment of the flooded rice field and its associated bacterial microflora are the cause for the lesser nitrogen requirement for the field decomposition of rice crop residues.

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