Fate of Fertilizer Nitrogen in a Flooded Rice Soil[1]

W. H. PATRICK,, JR., AND K. R. REDDY[2]

ABSTRACT

In order to improve the efficiency of fertilizer N utilization by rice (*Oryza sativa* L.), it is important to know what happens to N applied to the soil. Field experiments utilizing ^{15}N-enriched ammonium sulfate were carried out to determine the fate of fertilizer N (100 kg N/ha) applied to Crowley silt loam soil. The distribution of fertilizer N in the plant-soil system at harvest time was determined using 2.32 m^2 plots. The distribution of fertilizer N in the plant-soil-floodwater system at six times during the growing season was measured in smaller plots (0.28 m^2).

The results from the larger plots showed that fertilizer N recovered in the grain ranged from 30.9 to 37.3 kg N/ha depending on the method of application. Recovery of fertilizer N in the straw ranged from 18.2 to 24.2 kg N/ha. A considerable portion of fertilizer N (24.2 to 27.1 kg N/ha) remained in the soil (including roots) after cropping. Total recovery of the 100 kg/ha addition of labelled fertilizer N in the soil-plant system was 75.0 to 85.6 kg N/ha for the different methods of N application examined. Experiments using the smaller 0.28 m^2 plots showed rapid uptake of fertilizer N immediately after application, with no apparent further uptake after about 3 weeks. Soil N was the major and perhaps sole source of N for the plant during the last part of the growing season.

Additional Index Words: **rice fertilization, fertilizer N recovery, nitrogen loss, flooded soil, stable N isotope.**

FERTILIZER NITROGEN (N) is poorly utilized by rice (*Oryza sativa* L.) compared to many upland crops (Mitsui, 1954). In order to improve the efficiency with which rice utilizes N, it is important to determine the fate of fertilizer applied to lowland rice. To do this, it is necessary to use nitrogen fertilizer labelled with ^{15}N, so that the fertilizer N can be distinguished from soil N after addition to the soil. Studies conducted so far on N utilization by rice using labelled material have been restricted to greenhouse conditions, or to micro plots in the field (Broadbent and Mikkelsen, 1968; Broadbent and Nakashima, 1968; Patnaik and Broadbent, 1967; IAEA, 1970; Koyama et al., 1972; Muhammad et al., 1974; Yoshida and Padre, 1975). The shortage of field experiments is mainly due to the high cost of ^{15}N.

Although the studies cited above give an idea of the amount of fertilizer N utilized by rice, no information is available on the amount of fertilizer N remaining in the soil or lost from the plant-soil-water system under field conditions. The objective of the present investigation was to determine the distribution of applied labelled N in the soil-plant-water system at different growth stages of rice.

MATERIALS AND METHODS

The field experiments were conducted on Crowley silt loam (Typic Albaqualfs) at the Rice Experiment Station, Crowley, Louisiana. The soil had 0.8% total C and 0.08% total N contents. The pH of the soil was 5.8. The field was planted with 'Vista' rice variety at a rate of 90 kg/ha by drilling into rows 18 cm apart. The plots received a basal application of 22 kg/ha P and 41 kg/ha K at planting time. The field was flooded 27 days after seeding and maintained under continuous flooding (7 to 10 cm) during the entire growth period of the rice.

Different methods of N application were examined with respect to N recovery in the plant and soil system. The treatments used were:

1) All N applied by deep placement after seedling establishment (14 days after planting).
2) All N applied by surface application early in season (26 days after planting, or at tillering stage).
3) Half N applied by surface application early in season plus half N applied at midseason (53 days after planting, or at jointing stage).
4) No N applied (check).

After seedling establishment (10 days after planting), several subplots (each 2.32 m^2) were established in the experimental area. Aluminum barriers were fixed around each plot to prevent labelled N from moving out of the plot through the floodwater. Each treatment was replicated four times in a randomized block design. In an adjacent area, smaller circular microplots (0.28 m^2) with similar barriers received identical N treatments. These smaller plots were used to sample the whole plot for floodwater, soil, and plants at various times during the growing season. A single plot was used to sample each treatment during the growing season. The plants outside the plots adjacent to the barriers were pulled out before application of labelled fertilizer N to the smaller plots. All plots received a total of 100 kg N/ha as ammonium sulfate. The larger plots received material enriched with 8,801 atom % ^{15}N excess, and the smaller plots received material enriched with 5.216 atom % ^{15}N excess. Fertilizer N was applied either 7 cm deep in the soil or by the side of each row (on soil surface) in the form of pellets (approximately 4 to 8 mesh).

The plots of 2.32 m^2 size were sampled only at harvest time. The central five rows were harvested to determine labelled N recovery in grain and straw. After harvest, the soil (including the roots) was sampled by obtaining six soil cores (10 cm diam, 15-cm deep), and labelled N remaining in the soil was determined. The labelled N not recovered either in plant (grain and straw) or in the soil was assumed to be lost from the system. For the smaller plots

[1]Contribution from Laboratory of Flooded Soils and Sediments, Dep. of Agronomy, Louisiana Agric. Exp. Stn., Louisiana State Univ., Baton Rouge, LA 70803. This study was conducted cooperatively with TVA, Soil and Fertilizer Res. Branch, Div. of Agric. Develop. Received 8 Mar. 1976. Approved 5 May 1976.

[2]Professor, and Research Associate, respectively.

Table 1—Distribution of labelled fertilizer N at harvest time as influenced by different methods and times of N application (2.32 m^2 plots).†

N fraction	All N applied by deep placement	Topdressing: All N applied at early season	Topdressing: Half N at early season + half N at mid season
	kg/ha		
N in rice plant	49.1 ± 1.6	50.6 ± 6.9	61.4 ± 1.0
Grain	30.9 ± 0.5	32.1 ± 3.7	37.3 ± 2.3
Straw	18.2 ± 1.6	18.5 ± 3.3	24.1 ± 3.0
N remaining in soil (roots + soil)	25.9 ± 3.1	27.1 ± 3.0	24.2 ± 3.7
Total N recovered	75.0 ± 4.0	77.7 ± 8.9	85.6 ± 3.8
N unaccounted for	25.0 ± 4.0	22.3 ± 8.9	14.4 ± 3.8

† 100 kg N/ha was applied at the beginning of the growing season.

sampled throughout the season, single plots were analyzed at 32, 41, 53, 62, 75, and 88 days after planting. The floodwater in the microplots was carefully removed and sampled for inorganic N analysis. All plants with roots intact were carefully removed from the wet soil in the microplots. The roots were further separated from the shoots. The wet soil was removed from the small plot to a depth of 12.5 cm and transferred to a large tub and the fresh weight recorded. Then the wet soil was mixed thoroughly into a slurry. Duplicate subsamples were obtained and analyzed for total N (native soil N + fertilizer) and labelled N in the inorganic (ammonium + nitrate + nitrite) and organic fractions and for moisture content. Total N and labelled N in floodwater, shoots, and roots were also determined. Native soil N constitutes the nitrogen in the soil, other than labelled fertilizer N.

Analytical Methods

In the experiment using 2.32 m^2 plots, the grain, straw, and soil samples taken at harvest time were analyzed for total and labelled N contents (Bremner, 1965a). In the microplots, duplicate subsamples were extracted with 10% KCl (pH 2.5) and analyzed for total and labelled inorganic N. The remaining soil was then analyzed for total and labelled N, as were the floodwater samples. All plant samples obtained during the growing season were analyzed in duplicate for total and labelled Kjeldahl N. Labelled N analyses were made using a Dupont Model 21-614 mass spectrometer with an isotope-ratio attachment following the procedure given by Bremner (1965b).

RESULTS AND DISCUSSION

The recovery of fertilizer N in the soil and plant system in the 2.32 m^2 plots at harvest time is presented in Table 1. Approximately one-half to two-thirds of the applied N was recovered in the above-ground portion of the crop (grain and straw) for the three treatments. The grain contained 30.9 to 37.3% of the added N, and the straw contained 18.2 to 24.1%. Splitting the N application resulted in a larger fraction of the applied N in both the grain and straw fractions.

Since the isotopic fertilizer N used was enriched enough to maintain its identity when mixed with the much larger amount of soil N, it was possible to determine the amount of labelled N remaining in the soil. These data are also shown in Table 1. The total amount of fertilizer N remaining in the soil after cropping represented 24.2 kg N/ha in the plots receiving split application of N (half N as early season topdressing + half N as mid season topdressing) while 25.9 and 27.1 kg N/ha remained in the soil when N was applied by single application (all N applied by deep placement and all N applied as early season topdressing, respectively). The fertilizer N remaining in the soil was not present as inorganic N, but was incorporated into soil organic matter and rice roots.

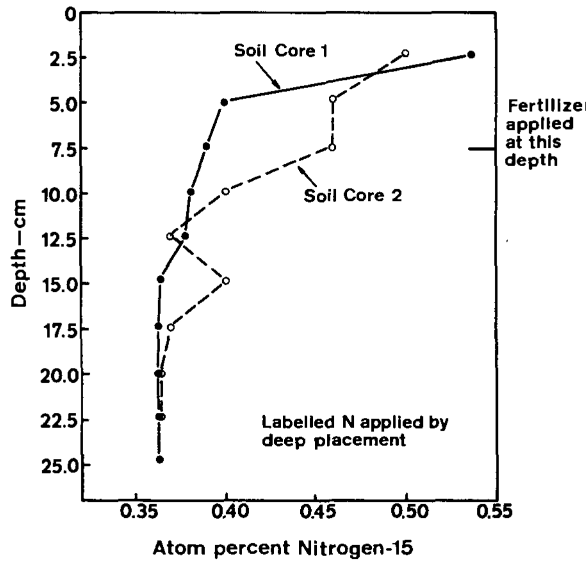

Fig. 1—Distribution of labelled N (expressed as atom % ^{15}N), with depth, when N was applied by deep placement.

Maximum recovery of applied N in plants and soil was obtained in the plots receiving fertilizer N by split application (85.6 kg N/ha) as compared to the plots receiving N by single application (75.0 and 77.7 kg N/ha). A considerable portion of applied N, ranging from 15 to 25 kg N/ha, was not accounted for. The unaccounted N can probably be attributed to N loss through biological reactions (nitrification-denitrification) although loss in runoff could have occurred. Small amounts of labelled N could possibly have leached or moved through the roots below the 0–15 cm sampling depths, but such a movement was not observed, as can be seen from Fig. 1, which shows the depth distribution of labelled N in the plots at the end of the growing season.

Uptake of Fertilizer and Soil Nitrogen by the Crop During Growing Season

The uptake of fertilizer N and native soil N during the growing season, as influenced by different methods of N application was measured in micro plots and is presented in Fig. 2. When all N was applied by deep placement immediately after seedling establishment (7 cm deep) or by early season surface application, all of the uptake occurred within a 3- to 4-week period after application with little further uptake. Soil N was taken up during the entire growing period and was the major and perhaps sole source of N during the latter part of the season. A small amount of labelled N immobilized immediately after application may have been mineralized along with native soil N and made available to the plant as the season progressed. When N was applied half as early season topdressing plus half as mid-season topdressing, most of the N applied during the second topdressing was probably taken up by the plant and accumulated in grain and straw (Fig. 2). In all the treatments studied, more native soil N was taken up by the rice as compared to the check plot where no N was applied. The results

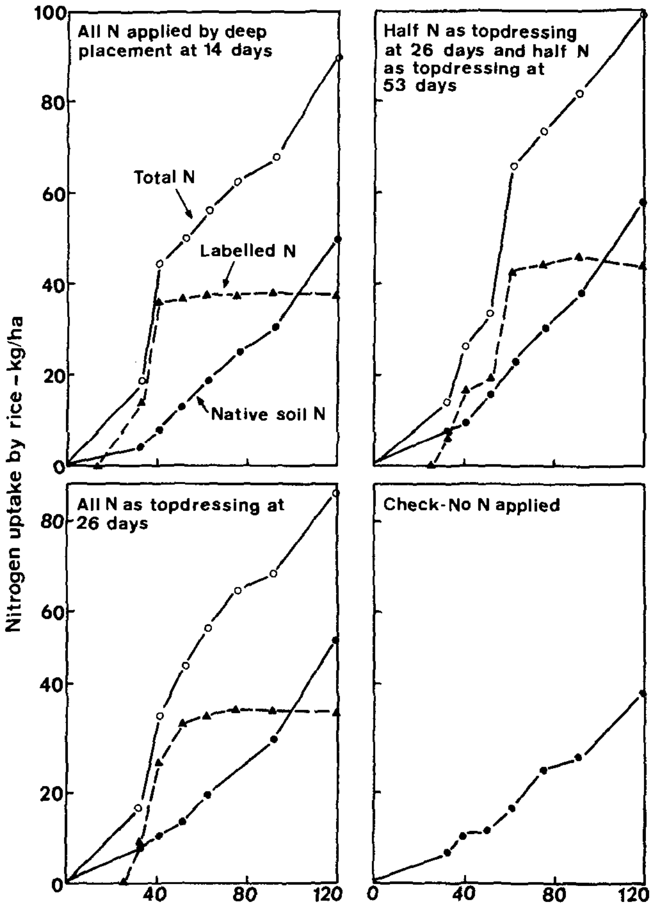

Fig. 2—Uptake of total, native, and labelled N fractions by rice, as influenced by different methods of N application.

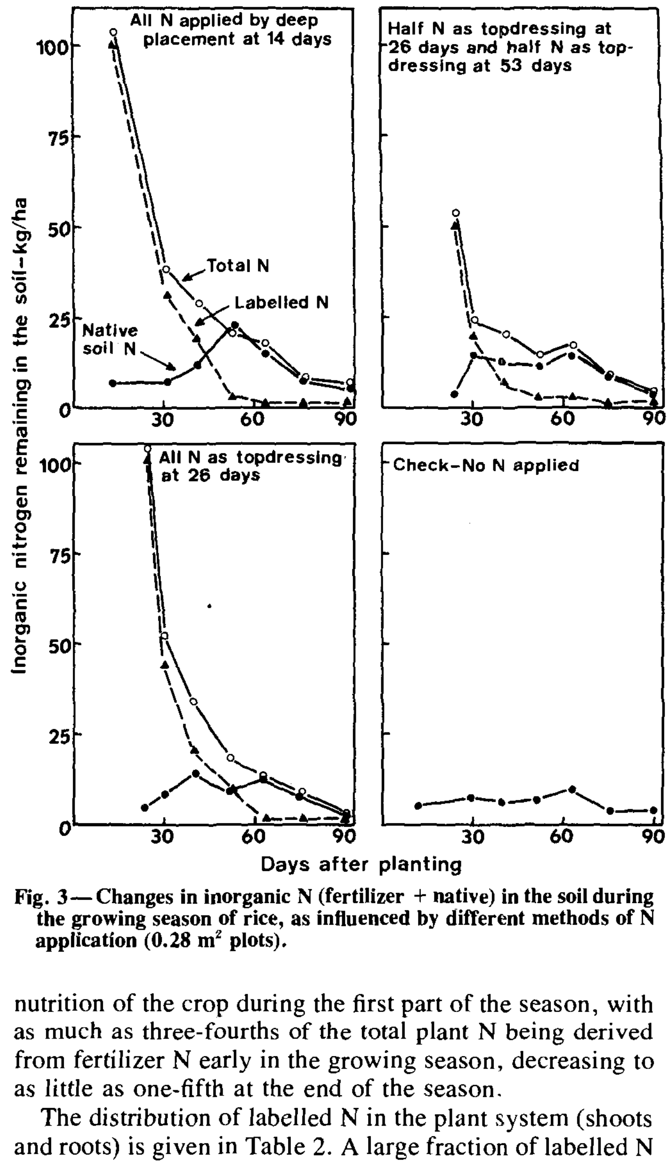

Fig. 3—Changes in inorganic N (fertilizer + native) in the soil during the growing season of rice, as influenced by different methods of N application (0.28 m² plots).

of this study show that the rice plant largely utilized fertilizer N during the early growth period with relatively less coming from native soil N, while during the latter part of the growth period, soil N was the major source of N for the plant with little fertilizer N uptake. It is possible that the apparent leveling off of fertilizer N uptake may not have resulted from a complete cessation of labelled N supply, but from the washing out of labelled N from the plant at approximately the same rate as it was being taken up. Patrick et al. (1974) also found that fertilizer N played a greater role in N nutrition of the crop during the first part of the season, with as much as three-fourths of the total plant N being derived from fertilizer N early in the growing season, decreasing to as little as one-fifth at the end of the season.

The distribution of labelled N in the plant system (shoots and roots) is given in Table 2. A large fraction of labelled N was accumulated in the shoots, and only a small fraction of labelled N was being recovered in the roots. These data indicate the rapid translocation of labelled N into the shoots during the growing season.

Table 2—Distribution of labelled fertilizer N in the plant system during growing season as influenced by difference methods and times of N application (0.28 m^2 plots).

N fraction	Days after planting					
	32	41	53	63	75	88
	kg/ha					
	All N applied by deep placement at 14 days					
Shoots	14.0	36.4	37.0	37.5	37.6	37.8
Roots	n.d.†	3.1	3.3	4.6	3.9	4.0
	All N applied as topdressing at 26 days					
Shoots	8.7	27.1	34.9	36.6	37.6	36.6
Roots	0.6	3.7	3.7	4.2	3.5	2.8
	Half N applied as topdressing at 26 days + half N applied as topdressing at 53 days					
Shoots	5.9	16.8	19.2	43.9	44.3	45.7
Roots	0.3	1.7	1.8	3.7	2.4	3.7

† Not determined.

Inorganic Nitrogen (Labelled + Native) in the Soil

Total inorganic N (mostly ammonium N) in the soil during the growing season is presented in Fig. 3. The total inorganic N (mostly applied fertilizer N) in the soil showed a rapid decline during the early part of the growing season and remained at a low value throughout the remainder of the season. The rapid decline in applied fertilizer N in the inorganic fraction during the early growing season can be ascribed to rapid plant uptake during the early part of the growth period of rice, immobilization into microbial tissue, loss of N through nitrification-denitrification reactions, and possibly some transport across the barrier around the plot. A major fraction of applied N was immobilized immediately after application of fertilizer N (2 weeks after application) and the labelled N content continued to decrease in the organic fraction during the growth period of the rice plant

Table 3—Distribution of labelled fertilizer N in the soil system during growing season, as influenced by different methods and times of N application (0.28 m² plots).

N fraction	Days after planting					
	32	41	53	63	75	88
	kg/ha					
	All N applied by deep placement at 14 days					
Soil system						
Inorganic N	31.4	18.3	2.7	2.0	0.8	0.1
Organic N	48.2	23.7	19.7	21.5	21.0	21.9
Floodwater	1.1	0.6	0.5	0.2	0.4	0.3
	All N applied as topdressing at 26 days					
Soil system						
Inorganic N	43.6	19.6	9.2	1.0	0.8	0.9
Organic N	38.6	25.3	20.4	20.9	20.2	17.9
Floodwater	1.6	1.1	0.4	0.2	n.d.†	0.3
	Half N applied as topdressing at 26 days + half N applied as topdressing at 53 days					
Soil system						
Inorganic N	20.8	6.6	2.0	2.0	1.1	0.9
Organic N	13.8	9.6	8.9	18.4	17.8	20.5
Floodwater	0.9	0.4	0.1	0.4	n.d.†	0.3

† Not determined.

Table 4—Distribution of labelled fertilizer N during growing season in the soil-plant system as influenced by different methods and times of N application (0.28 m² plots).

N fraction	Days after planting					
	32	41	53	63	75	88
	kg/ha					
	All N applied by deep placement at 14 days					
Plant	14.0	39.5	40.3	42.1	41.5	41.8
Soil	80.7	42.6	22.9	23.1	22.2	22.3
Total	94.7	82.1	53.2	65.8	63.7	64.1
N-unaccounted for	5.3	17.9	36.8	34.2	36.0	35.9
	All N applied as topdressing at 26 days					
Plant	9.3	30.8	38.6	40.8	41.1	39.4
Soil	83.8	46.0	30.0	22.1	21.0	19.1
Total	93.1	76.8	68.6	62.9	62.1	58.5
N unaccounted for	6.9	23.2	31.4	37.1	37.9	41.5
	Half N applied as topdressing at 26 days + half N applied as topdressing at 53 days					
Plant	6.2	18.5	21.0	47.6	46.7	49.4
Soil	35.5	16.6	11.0	20.8	18.9	21.7
Total	41.7	35.1	32.0	68.4	65.6	71.4
N unaccounted for	8.3	14.9	18.0	31.6	34.4	28.6

(Table 3). At all growth stages of rice, a small fraction of fertilizer N was recovered in the overlying floodwater.

The fertilizer N lost from the soil-plant system at different times during the growing season of rice is shown in Table 4. Most of the applied N that was lost disappeared during the early part of the growing season (4 to 6 weeks after planting). This early season loss was very likely due to more fertilizer N being present in the inorganic form than could be immediately utilized by the plant and being subject to nitrification-denitrification reactions.

The net recovery of labelled N in the plant system was slightly lower in the microplots (0.28 m²) than in the macroplots (2.32 m²). Even though the plants adjacent to the microplots were removed, there could have been uptake of labelled N by plants outside the plots, which resulted in reduced recovery of labelled N in the plot. Any possible border effect was controlled in the 2.32 m² plots by harvesting the central five rows and leaving two border rows on each side. Although the floodwater level was maintained at about the same level inside and outside the plots, some movement of soluble N across the barrier could possibly have occurred. This would have been more pronounced in the smaller plots.

The results of this study showed that at harvest time, approximately one-third of fertilizer N applied to rice was recovered in the grain, approximately one-fifth to one-fourth was recovered in the straw, approximately one-fourth remained in the soil and roots, with the remaining one-fifth to one-fourth of the added N lost from the system. Determining the fate of added N at various times throughout the growing season showed rapid uptake immediately after application with little uptake beyond three weeks. Soil N was apparently almost the sole source of N during the last part of the growing season.

LITERATURE CITED

1. Bremner, J. M. 1965a. Total nitrogen. *In* C. A. Black et al. (eds.) Methods of soil analysis. Part 2. Agronomy 9:1149–1176. Am. Soc. of Agron., Madison, Wis.
2. Bremner, J. M. 1965b. Isotope ratio analysis of nitrogen in N-15 tracer investigations. *In* C. A. Black et al. (eds.) Methods of soil analysis. Part 2. Agronomy 9:1256–1286. Am. Soc. of Agron., Madison, Wis.
3. Broadbent, F. E., and D. S. Mikkelsen. 1968. Influence of placement on uptake of tagged nitrogen by rice. Agron. J. 60:674–677.
4. Broadbent, F. E., and T. Nakashima. 1968. Plant uptake and residual value of six tagged nitrogen fertilizers. Soil Sci. Soc. Am. Proc. 32:388–392.
5. International Atomic Energy Agency. 1970. Rice fertilization. A six year study on nitrogen and phosphorus fertilizer utilization. Vienna, Austria. Fertilizer Abstr., 4:24, 1971.
6. Koyama, Takeo, Chittana Chammek., and Natee Niamsrichand. 1972. Soil-plant nutrition studies on tropical rice. V. Yield components as affected by the timing of topdressing of nitrogen in the Bangkhen paddy field. Soil Sci. Plant Nutr. 18:233–245.
7. Mitsui, S. 1954. Inorganic nutrition, fertilization and amelioration for lowland rice. Yokendo Ltd., Tokyo. p. 107.
8. Muhammad, Shah, Ung Ju. Kim, and Kikuo Kumazaqua. 1974. The uptake, distribution and accumulation of ^{15}N labelled ammonium and nitrate nitrogen top-dressed at different growth stagesiof rice. Soil Sci. Plant Nutr. 20:279–286.
9. Patnaik, S., and F. E. Broadbent. 1967. Utilization of tracer nitrogen by rice in relation to time of application. Agron. J. 59:287–288.
10. Patrick, W. H., Jr., R. D. DeLaune, and F. J. Peterson. 1974. Nitrogen utilization by rice using ^{15}N depleted ammonium sulfate. Agron. J. 66:819–820.
11. Yoshida, T., and B. C. Padre, Jr. 1975. Effect of organic matter application and water regimes on the transformation of fertilizer nitrogen in a Philippine soil. Soil Sci. Plant Nutr. 21:281–292.