Nitrogen Cycle in Paddy Fields

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Research on nitrogen cycle in paddy fields, that is composed of mineralization, immobilization, denitrification, leaching, and absorption by rice plants of nitrogen applied and of soil nitrogen, as well as biological nitrogen fixation, is regarded to be important for the field management to maintain a long-term and stable productivity.

From this point of view, the author carried out a series of ^{15}N tracer experiments in the experimental fields of the Station, and also by using lysimeters. For the field experiment, two fields with different soils were used: (1) heavy-clayey strong gley soil (semi ill-drained paddy field) and (2) heavy-clayey gley soil (the above field was converted to an upland field condition and then returned to paddy field: By doing so, the paddy field was changed to a well drained condition. This field is referred to as converted well-drained field). In the lysimeter experiment, various kinds of soils were used with two different treatments, simulating a well-drained and an ill-drained condition.

At each stage of seedling-rooting, tillering and panicle initiation, nitrogen labelled with ^{15}N was applied at the rate of 4 g/m^2, and its fate, especially that of mineralized nitrogen was examined.

Experimental methods

1) Methods to assess amount of immobilization, denitrification, and absorption by rice plants of applied nitrogen

(1) Setting of ^{15}N plots and soil- and plant-sampling

Number of tillers/hill was counted with all plants (in case of field of about 4–10 m^2) or with 50 plants (in case of field larger than 50 m^2) to know the average number of tillers/hill. The hills showing the average number of tillers were selected as representative hills. Each representative hill was surrounded by a wooden frame enclosing an area similar to the planting space, for example 18 cm×30 cm. The frame was put into the field to a depth of about 20 cm (the height of the frame: 30 cm). The solution of nitrogen fertilizer labelled with ^{15}N was applied to the soil inside the frame, and after a certain number of days, the rice plants and the soil inside the frame were all sampled, mixed thoroughly, and then used for analysis. Values of atom % of ^{15}N in the samples were measured with an Emission spectrometer.[5]

(2) Estimation of denitrification of applied nitrogen

Denitrification of applied nitrogen was estimated by subtracting amount of immobilized nitrogen and absorbed nitrogen by rice plants from the total amount of applied nitrogen,[4] because losses of nitrogen caused by leaching to subsoil and volatilization in the form of NH_3 and NO_2 were negligible.

2) Estimation of immobilization, denitrification, and absorption by rice plants of mineralized soil nitrogen

(1) Amount of absorption by rice plants of mineralized soil nitrogen

It can be obtained by subtracting the amount of applied nitrogen absorbed by rice plants from the total amount of nitrogen absorbed by the rice plants. Nitrogen supplied by irrigation water was also absorbed by rice plants, but it was only about 0.2 g/m^2 during a growing period, and hence neglected.

(2) Total amount of soil nitrogen mineralized in the whole period of growth

Table 1. Immobilization, denitrification, and absorption by rice plants of nitrogen applied to paddy soils, as revealed by the ^{15}N tracer experiment and shown by percentages(6)

Plot No.	Soils	Drainage condition	Flooding irrigation	Compost (t/10a)	Immobilization Nitrogen applied at R(3)	T(4)	P(5)	Denitrification Nitrogen applied at R	T	P	Absorbed by rice plants Nitrogen applied at R	T	P
1	Sandy	Ill(1)	+(2)	–	30.2	21.1	24.3	48.8	15.0	6.9	21.0	63.9	68.8
2		Well	+	–	21.9	12.7	14.9	66.8	32.4	16.9	11.3	54.9	68.2
3	Heavy clayey	Ill	+	–	42.2	19.4	26.6	32.0	13.1	14.0	25.8	67.5	59.4
4		Well	+	–	29.0	21.6	24.8	54.6	29.2	16.3	16.4	49.2	58.9
5	Peat	Ill	+	–	42.5	30.6	30.2	24.9	5.2	8.6	32.6	63.5	61.2
6		Well	+	–	40.9	30.8	25.8	38.4	12.7	23.2	20.7	56.5	51.0
7	Heavy clayey	Semi-ill	+	–	50.3	27.0	22.4	23.8	25.1	10.7	25.9	47.9	66.9
8		Semi-ill	–	–	44.5	24.7	18.3	32.4	22.2	20.1	23.1	54.1	61.6
9		Well	+	–	42.7	12.0	12.1	33.3	35.6	22.0	24.0	52.4	65.9
10		Well	–	–	35.3	13.3	15.7	40.1	43.1	28.6	24.6	43.6	55.7
11		Semi-ill	+	0	48.6	28.4	23.2	29.9	19.0	8.1	21.5	52.6	68.7
12		Semi-ill	+	1	37.8	22.8	23.2	44.9	28.4	10.0	18.5	48.8	66.8
13		Semi-ill	+	2	41.8	24.7	21.7	37.2	30.3	10.0	21.0	45.0	68.3
14		Semi-ill	+	3	42.0	21.0	24.7	39.0	28.6	10.2	19.0	50.4	65.1

Notes Plot No. 1–6: lysimeter experiment, No. 7–14: field experiment, No. 9 and 10: converted well-drained fields.
(1) Ill: ill-drained, Well: well-drained, Semi-ill: semi-ill-drained.
(2) + : flooding irrigation, –: non-flooding.
(3) R : seedling-rooting stage.
(4) T : tillering stage.
(5) P : panicle initiation stage.
(6) Percentage to the total amount of nitrogen applied at each stage.

duration and its immobilization and denitrification

These values can be obtained by the isotope dilution method[2] using ^{15}N, and amount of absorbed soil nitrogen by rice plants.[6]

3) Biological nitrogen fixation in paddy soils

(1) Method of estimation

(Amount of decrease in total soil nitrogen) + (amount of absorbed nitrogen contained in top part of rice plants) + (volatilization and leaching loss; in this case denitrification loss) – (total amount of nitrogen applied) gives the estimation.

(2) Method of measurement

Water, in which air containing ^{15}N is dissolved, was applied, and its atom % was measured at a given time interval. The same procedure was repeated by renewing the water containing ^{15}N. Finally, the amount of nitrogen fixation was calculated from the mean value of atom % of ^{15}N in water and that of atom % of soil.

Results and discussions

1) Immobilization, denitrification and absorption by rice plants of applied nitrogen

Table 1 shows the fate of applied nitrogen, i.e., immobilization, denitrification, or absorption by rice plants. They are shown by percentages.

(1) Immobilization of applied nitrogen in paddy soils

Percentage of immobilization was greater for nitrogen applied at the seedling-rooting stage than that applied in the tillering or the panicle initiation stage. The former was 1.5–4 times as great as the latter. Comparisons between well-drained and ill-drained fields showed no

Table 2. Immobilization, denitrification, and absorption by rice plants of mineralized soil nitrogen, as revealed by ^{15}N tracer experiment and shown by N kg/10a

Soil	Condition & management	Fate [a]	May 19–[b] June 18	June 18–July 16	July 16–Aug. 16	May 19–Aug. 16	May 19–Aug. 16 (Fertilizer)
Sandy	Ill-drained, flooding	I	0.60	1.30	0.86	2.76	3.02
		A	1.01	3.62	2.44	7.07	6.15
		D	0.75	0.72	0.25	1.72	2.83
		M	2.36	5.64	3.55	11.55	12.00
	Well-drained, flooding	I	0.58	0.85	0.95	2.38	1.98
		A	1.11	3.02	2.97	7.10	5.38
		D	1.66	2.40	0.92	4.98	4.64
		M	3.36	6.29	4.84	14.49	12.00
Heavy clayey	Ill-drained, flooding	I	0.78	1.68	0.98	3.44	3.53
		A	1.18	4.37	2.18	7.73	6.11
		D	0.57	1.01	0.51	2.09	2.36
		M	2.52	7.08	3.67	13.27	12.00
	Well-drained, flooding	I	0.90	2.10	1.31	4.31	3.02
		A	1.17	4.67	3.11	8.95	4.98
		D	1.49	2.15	0.86	4.50	4.00
		M	3.56	8.92	5.28	17.76	12.00
Heavy clayey	Semi-ill-drained, flooding	I	1.90	1.46	0.88	4.24	3.99
		A	0.98	3.39	2.62	6.99	5.63
		D	0.90	1.06	0.42	2.38	2.38
		M	3.78	5.91	3.92	13.61	12.00
	Semi-ill-drained, no flooding	I	1.42	1.14	0.82	3.38	3.50
		A	0.74	3.07	2.76	6.57	5.55
		D	1.04	1.12	0.90	3.06	2.99
		M	3.20	5.31	4.48	12.99	12.00
	Well-drained, flooding	I	1.60	0.93	0.47	3.00	2.67
		A	0.90	4.58	2.54	8.02	5.69
		D	1.25	2.22	0.85	4.32	3.64
		M	3.75	7.74	3.85	15.34	12.00
	Well-drained, no flooding	I	1.30	0.48	0.41	2.19	2.57
		A	0.90	1.63	1.44	3.97	4.96
		D	1.46	1.34	0.74	3.54	4.47
		M	3.66	3.44	2.60	9.70	12.00
Heavy clayey	Semi-ill-drained, compost 0	I	2.30	1.46	0.80	4.56	4.01
		A	1.02	3.42	2.38	6.82	5.71
		D	1.42	0.76	0.28	2.46	2.28
		M	4.74	5.64	3.46	13.84	12.00
	Semi-ill-drained, compost 1	I	1.80	1.66	0.92	4.38	3.34
		A	0.88	4.16	2.65	7.69	5.34
		D	2.14	1.38	0.40	3.92	3.32
		M	4.76	7.20	3.97	15.93	12.00
	Semi-ill-drained compost 2	I	0.98	0.90	1.11	2.99	3.53
		A	0.49	2.19	3.48	6.16	5.37
		D	0.86	0.78	0.51	2.15	3.10
		M	2.33	3.87	5.10	11.30	12.00
	Semi-ill-drained, compost 3	I	1.21	0.75	1.49	3.45	3.51
		A	0.55	1.89	3.94	6.38	5.38
		D	1.13	0.63	0.62	2.38	3.11
		M	2.89	3.27	6.05	12.21	12.00

Note: (a) I: immobilization, A: absorption by rice plants, D: denitrification and M: mineralization.

(b) May 19, 1980.

appreciable difference in heavy clayey soil and peat soil, but the immobilization occurred to a less extent in well-drained sandy soil than ill-drained one. As to the kinds of soil, peat soil showed a greater extent of immobilization than sandy soil and heavy clayey soil.

The semi-ill-drained field showed a greater extent of immobilization than the converted well-drained field at each growing stage. Comparison between flooding irrigation and non-flooding irrigation for these fields showed a greater immobilization by flooding irrigation for the semi ill-drained field, but for the converted well drained field no difference was observed except an increased immobilization at the initial stage of seedling-rooting by the non-flooded irrigation.

Effect of compost application on immobilization of applied nitrogen was examined in the semi-ill-drained field. The result showed a trend of less immobilization by compost application.

(2) Absorption of applied nitrogen by rice plants

Ratio of utilization by rice plants increased with the advance of plant growth: from seedling-rooting stage to tillering stage, and to panicle initiation stage. It was greater in ill-drained fields than in well-drained fields. As to the kinds of soil, it was peat soil>heavy clayey soil>sandy soil at the seedling-rooting stage for both ill-drained and well-drained fields but the difference by the soils disappeared in the tillering stage and panicle initiation stage, showing 61–69% in ill-drained fields and about 50% in most well-drained fields.

Comparison between the semi-ill-drained field and the converted well-drained field showed no difference at each stage in flooded plots, but a greater absorption in the semi-ill-drained field in non-flooded plots. The flooding and non-flooding irrigation gave no appreciable difference in the absorption for semi-ill-drained field, but for the converted well-drained field the flooded plot gave a higher absorption ratio of nitrogen applied at the tillering and panicle initiation stages.

Effect of compost application examined in the semi ill-drained field showed a tendency that the ratio of nitrogen utilization by rice plants was lowered by compost application.

(3) Denitrification of applied nitrogen in paddy soils

The denitrification showed a tendency that it was the highest at the seedling-rooting stage, and it lowered in the tillering stage, followed by further lowering in the panicle initiation stage. It was higher in well-drained fields than ill-drained fields. As to the kinds of soil, it was sandy soil>heavy clayey soil>peat soil at the seedling-rooting and the tillering stage in both ill-drained and well-drained plots.

As compared with the semi-ill-drained field, the converted well-drained field showed a higher ratio of denitrification. As to the flooding and non-flooding irrigation, the latter tended to show higher ratios of denitrification in both fields. Ratio of denitrification was equally high at the seedling-rooting stage and the tillering stage, and it lowered at the panicle initiation stage. Compost application increased denitrification in the semi-ill-drained field examined.

2) Immobilization, denitrification and absorption by rice plants of mineralized soil nitrogen

Table 2 shows the fate of mineralized soil nitrogen, i.e., immobilization, denitrification, and absorption by rice plants.

(1) Mineralized nitrogen in soils

Amount of mineralized nitrogen in soils was more in the well-drained fields than in the ill-drained fields at each growing stage, and the difference during the growing season was 4–5 kg/10a. This tendency was observed in the comparison between the converted well-drained field and the semi-ill-drained field. However, the flooded plots showed more amount of mineralized nitrogen than the non-flooded plots. Effect of organic matter application was examined in the semi-ill-drained field, with the result that the standard rate of application gave the greatest amount of mineralized nitrogen, followed by the non-application, but higher rates reduced its amount.

(2) Immobilization of mineralized soil nitrogen

Amount of nitrogen immobilized from mineralized soil nitrogen was, in general, greater in the ill-drained fields than in the well-drained fields, but in case of the heavy clayey soil, which showed a big difference in amount of mineralized nitrogen between ill-drained plot and well-drained plot, the latter came to show a greater amount of immobilized nitrogen. As there was no big difference in amount of mineralized nitrogen between the semi-ill-drained field and the converted well-drained field, the amount of immobilized nitrogen was slightly greater in the former than the latter. In both fields, it was greater in flooded plot than in non-flooded plot. It was reduced by organic matter application: compost application at the rate of 2–3 ton/10a reduced it to about 70% of that of non-application.

(3) Absorption by rice plants of mineralized soil nitrogen

Amount of absorption was generally greater in the well-drained fields than in the ill-drained fields. However, when there was a big difference in amount of total nitrogen between the two fields as in the case of sandy soil, the both fields showed a similar amount of absorption. The converted well-drained field showed a greater absorption than the semi ill-drained field. In both fields, the absorption was greater in the flooded plot than the non-flooded plot. Organic matter application at the standard rate gave the greatest absorption, followed by the non-application. Heavy application of organic matter (compost 2–3 t/10a) reduced the absorption, and even though the amount of absorption was increased in later growth period, it still showed a difference of about 1.5 kg/10a from the standard rate (compost 1 t/10a).

(4) Denitrification of mineralized soil nitrogen

The well-drained fields showed more denitrification than the ill-drained fields. Similarly, the converted well-drained field showed more denitrification than the semi-ill-drained field. In the latter field, the denitrification occurred more in the non-flooded plot than the flooded plot, but in the former the flooded plot showed more denitrification, as a result of big difference in amount of mineralized nitrogen between the two plots.

The standard rate of organic matter application showed an increase of denitrification by 1.5 kg/10a over the non-application, but the heavy application showed a slightly less denitrification than the non-application, due to less amount of mineralization.

(5) Effects of water management on mineralization of soil nitrogen

The non-flooded irrigation causes drying of plow layer, and hence a decrease in liquid phase. However, the decreased liquid phase does not induce an increase of gaseous phase, but results in an increase of solid phase, with the formation of constricted and compacted soil layer. As the heavy clayey paddy soil containing a montmorillonite clay mineral strongly undergoes this change, a soil volume shrinkage and a soil density increase occur, with a result of formation of constricted and compacted horizon,[1] which makes it difficult for soil microorganisms to enter among soil particles and absorb soil nutrients. As a result, it is considered that the mineralization of nitrogen must be strongly suppressed.

3) Biological nitrogen fixation in paddy soils

The amount of fixed nitrogen in the heavy clayey, well-drained field was calculated at 6.5 kg/10a. Similarly that for the heavy clayey, ill-drained field, flooded plot of the semi ill-drained field, and flooded plot of the converted well-drained field was estimated at 5.2, 4.7 and 5.9 kg/10a, respectively. Result of actual measurements of nitrogen fixation done by using ^{15}N in the flooded plot of the heavy clayey semi-ill-drained field was as follows: ^{15}N atom % of the water with dissolved air labelled with ^{15}N was 5.13 immediately before the application. Mean atom % of the water during the use was 2.32. On the other hand atom % of the soil after repeated application of the water for 9 days was 0.379 for 0–1 cm of soil depth, 0.373 for 1–2 cm, 0.369 for 2–4 cm, and 0.366 atom % for each of 4–6, 6–8, and 8–10 cm. Therefore, if we assume that the nitrogen fixation continues at the same rate as above for the whole growing period, the total amount of fixed nitrogen becomes 4 kg/10a.

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