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SOIL AND FERTILIZER NITROGEN TRANSFORMATIONS UNDER ALTERNATE FLOODING AND DRYING MOISTURE REGIMES

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KEY WORDS

Ammonification Mineral nitrogen recovery Nitrapyrin (N-Serve) Nitrification Soil drying Soil pH

SUMMARY

A study of changes in NH_4^+ and NO_3^--N in Maahas clay amended with $(NH_4)_2SO_4$ and subjected to 4 water regimes in the presence and absence of the nitrification inhibitor N-Serve (Nitrapyrin) showed that the mineral N was well conserved in the continuous regimes of 50% and 200% (soil weight basis) but suffered heavy losses due to nitrification-denitrification under alternate drying and flooding. N-Serve was effective in minimizing these losses.

Another incubation study with 3 soils showed that after 10 cycles of flooding and drying (either at 60°C or 25°C), the ammonification of soil N was enhanced. Nitrification of soil as well as fertilizer NH_4^+ was completely inhibited upto 4 weeks by the treatments involving drying at high temperature. Flooding and air drying at 25°C, on the other hand, enhanced ammonification of soil N but retarded nitrification. These treatments, however, enhanced both ammonification and nitrification of the applied NH_4^+ fertilizer N. Under flooded conditions rate of NH_4^+ production was faster in soils that were dried at 60°C or 25°C and then flooded as compared to air dried soils.

It is concluded that N losses by nitrification-denitrification and related N transformations may be considerably altered by alternating moisture regimes. Flooding and drying treatments seem to retard nitrification of soil N but conserve that of fertilizer NH_4^+ applied after these treatments.

INTRODUCTION

An appreciable part of both native and applied N in flooded rice soils is lost by nitrification-denitrification. NH_4^+ released from soil organic matter or added as fertilizer is converted to NO_3^- in the localized aerobic zones of the submerged soils. When the dissolved NO_3^--N enters the anaerobic zone by mass flow or by diffusion it is rapidly denitrified[8,10]. Nitrogen losses also occur when a flooded soil undergoes alternate drying and flooding[9]. Studying the nitrification-

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denitrification reactions in flooded soils, Patrick and Reddy[8] emphasized the role of NH_4^+ diffusion and oxygen availability for nitrification as the limiting factors for nitrification-denitrification losses.

It is also known that wetting and drying of soils stimulate decomposition of organic matter due to what is called the 'Birch effect' and this results in flush of inorganic N after each cycle of drying and wetting[1,2,3]. However, little information is available on the effects of flooding and drying treatments on the transformations of fertilizer N applied after these treatments and also the pattern of ammonification and nitrification of soil as well as fertilizer N. The objectives of the work reported here were: i) to study the influence of moisture regimes and nitrification inhibitor on transformation of fertilizer N; and ii) to study the effects of alternate flooding and drying cycles on the subsequent mineralization and nitrification of soil and nitrification of applied fertilizer N.

Table 1. Analysis of soils

Soil	pH (1:1)	O.M. (%)	Total N (%)
Maahas clay	6.65	2.5	0.12
Luisiana clay	4.40	3.2	0.18
Pila clay	7.50	3.8	0.19

MATERIALS AND METHODS

The soils used (Table 1) were surface (0–15 cm) samples of Maahas clay, Luisiana clay and Pila clay. The soil samples were air dried and crushed to pass a 2-mm screen before use. For soil analyses in Table 1, pH was measured by a glass electrode; organic C analysis was done by Walkley and Black[15] method and total N was determined by the method described by Bremner[4].

Experiment No. 1

The soil samples of Maahas clay fertilized with 100 μg N/g of soil as $(NH_4)_2SO_4$ were subjected to the following combinations of water-regimes and concentrations of N-Serve inhibitor [2-chloro-6 (trichloromethyl) pyridine]. (*See table next page*).

Twenty g of soil was placed in 125 ml Erlenmeyer flasks. Nitrogen in water and N-Serve in acetone were first mixed and then added to the soil and thoroughly mixed. More water was then added to bring the soil moisture content to the desired level. An equal amount of acetone was added to the treatments, without N-Serve. The flasks were gently shaken and left open for about 2 h and were then covered with aluminum foil and incubated at 30°C for 7 weeks. Before incubation, weights of each flasks were recorded and were used to make up the loss of water twice a week. Initial readings of NH_4^+ and NO_3^--N was taken after about 2 hours of equilibration of the samples. Nitrate and ammonium nitrogen were analysed by extracting the soils with 2 *N* KCl and followed by distillation

Treatment	N-Serve (Nitrapyrin) (μg/g of soil)	Water regime (% by wt)
1	0	50% continuously
2	0	100% continuously
3	0	200% continuously
4	0	200% alternating with 50%
5	2	50% continuously
6	2	100% continuously
7	2	200% continuously
8	2	200% alternating with 50%

with Devarda's alloy and MgO[5]. The final soil: extractant ratio used was 1 : 10. Two replicates of each soil treatments were analyzed for NH_4^+-N and NO_3^--N after 1, 3, 5 and 7 weeks of incubation.

Experiment No. 2

In this experiment 200 g portions of Maahas, Luisiana and Pila clays were subjected to 10 cycles of flooding and drying. One cycle of flooding and drying was completed in four days, allowing the soils to remain flooded and dry for 2 days each. Flooding was done by adding 400 ml of water and the soils were completely dried in an electric oven at 60°C. In another treatment the soil samples were subjected to 10 cycles of flooding and drying at room temperature (25°C). One cycle was completed in about 2 weeks. After these treatments, the soils were air dried and again ground to pass 2 mm sieve. These soils along with the air-dry untreated check samples were incubated under flooded as well as aerobic (50% WHC) conditions at 30°C for 4 weeks. Ten g soil samples were incubated in 125 ml conical flasks covered with aluminum foil. To study the mineralization of NH_4^+-N, the samples were incubated after applying 200 ppm of NH_4^+-N as ammonium sulfate under aerobic conditions. The samples were analyzed in duplicate for NH_4^+ and NO_3^--N after 4 weeks of incubation following extraction with 2 *M* KCl solution and steam distillation with MgO and Devarda's alloy as described by Bremner[5].

RESULTS AND DISCUSSION

Experiment No.1

The nitrification of ammonium sulfate was fast at 50% moisture regime and by the third week about 71% of the fetilizer nitrogen had been nitrified. N-Serve effectively inhibited nitrification at 50% soil moisture content and only about 21% of the NH_4^+-N was nitrified during the same period of incubation (Table 2). In the 100 and 200% moisture regimes, ammoniacal nitrogen was the major form, however, there was some nitrate formation at 100% soil moisture, which was also suppressed by N-Serve. But after 7 weeks there was no nitrate detected either at 100 or 200% soil moisture with or without the inhibitor treatment. The recovery of applied NH_4^+-N was not quantitative even after equilibration for 2 h (see zero day reading in Table 2) because the soil fixes ammonium[13,14].

Table 2. Influence of water regime and N-Serve on nitrification of fertilizer NH_4^+-N (expressed as parts/10^6)

Water regime (%)	Duration*	N-Serve (ppm)	Weeks incubated									
			0		1		3		5		7	
			NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-
50	C	0	79	12	44	46	19	71	12	81	8	84
50	C	2	80	12	72	15	56	21	41	45	20	68
100	C	0	78	13	63	21	61	8	59	2	64	0
100	C	2	81	12	80	11	82	3	74	1	75	0
200	C	0	82	12	79	1	84	1	79	1	81	0
200	C	2	82	12	89	1	85	0	87	0	83	0
200/50	A	0	81	12	83	2	22	38	22	7	6	18
200/50	A	2	81	12	82	2	65	13	67	4	43	13

C: Continuously at 50% moisture by weight of soil.
A: Alternately at 200% (for 1st and 3–5 weeks) and 50% moisture (for 1–3 and 5–7 weeks).

Table 3. Effect of water regimes and N-Serve on the recovery of inorganic nitrogen

Water regime (%)	N-Serve (μg/g of soil)	Initial* total mineral N (parts/10^6)	Final (after 7 weeks) total mineral N (parts/10^6)	N recovery (%)
50, continuous	0	147	92	62
50, continuous	2	147	82	56
100, continuous	0	147	64	44
100, continuous	2	147	75	51
200, continuous	0	147	81	55
200, continuous	2	147	83	56
200 and 50 alternately	0	147	24	16
200 and 50 alternately	2	147	56	38

* This includes 100 parts/10^6 NH_4^+-N applied and the amount of inorganic nitrogen present in soil.

Fertilizer nitrogen was well conserved at 50, 100 and 200% moisture regimes but there was considerable loss of the nitrogen under fluctuating water regimes and in one cycle of flooding and drying about 60 ppm of nitrogen was lost (Table 2 and 3). N-Serve seemed to minimize these losses and at 7 weeks the inhibitor-treated soil contained double the amount of inorganic nitrogen as compared to the untreated control (Table 3). These results are in accordance with those of Prasad and Rajale[11], who found that N-Serve reduced losses of urea nitrogen under alternate flooding and drying conditions. Heavy losses of N under laboratory studies due to alternate flooding and drying have been reported by other workers[6,9,12].

The results from this study indicate that there can be enormous losses of nitrogen due to nitrification-denitrification under the alternate flooding and drying conditions so often encountered in rice soils. The nitrification inhibitors like N-Serve seem to have some scope in minimizing these losses.

Experiment No. 2

The changes in the pH of the soils by repeated wetting and drying cycles are shown in Table 4. They indicate that the pH of Maahas and Pila soils increased after the treatment, while that of Luisiana clay was depressed a little. Air drying had little if any effects on the pH of the soils. The increase in the pH of Maahas and Pila soils may be probably due to hydrolysis of clay minerals and partly due to removal of carbon dioxide from the soils during repeated wetting and drying. This increase in pH may also be due to accumulation of ammonia and stopping of

Table 4. Effects of wetting and drying on the pH of soils

Soil	pH of the soil (1 : 1) in water		
	Before treatment	After treatment	
		Dried at 60°C	Air dried 25°C
Maahas clay	6.35	7.06	6.40
Luisiana clay	4.34	4.27	4.34
Pila clay	7.60	8.02	7.76

Table 5. Effects of alternate flooding and drying moisture regime on the subsequent release of NH_4^+-N under anaerobic incubation at 30°C for 4 weeks

Soil	Treatments	NH_4^+-N (parts/10^6)
Maahas clay	No flooding or drying	28
Maahas clay	Flooded and air dried	44
Maahas clay	Flooded and dried at 60°C	65
Luisiana clay	No flooding or drying	112
Luisiana clay	Flooded and air dried	118
Luisiana clay	Flooded and dried at 60°C	135
Pila clay	No flooding or drying	103
Pila clay	Flooded and air dried	110
Pila clay	Flooded and dried at 60°C	113

Table 6. Effects of repeated flooding and drying on nitrification of fertilizer NH_4^+-N in soils incubated aerobically at 30°C for 4 weeks

Soil	Treatment	ppm of inorganic N		Rate of nitrification (%)
		NH_4^+-N	NO_3^--N	
Maahas clay	No flooding or drying	19	152	76
Maahas clay	Flooding and air drying	23	174	87
Maahas clay	Flooding and drying at 60°C	165	0	0
Luisiana clay	No flooding or drying	188	0	0
Luisiana clay	Flooding and air drying	293	0	0
Luisiana clay	Flooding and drying at 60°C	212	0	0
Pila clay	No flooding or drying	12	144	72
Pila clay	Flooding and air drying	18	179	89
Pila clay	Flooding and drying at 60°C	159	0	0

nitrification due to drying at 60°C. It is however difficult to explain the little change in the pH of Luisiana clay because its pH was slightly decreased after these treatments, which may be due to removal of exchange acidity from the soil exchange due to repeated wetting and drying.

Results in Tables 5 and 6 clearly show that the mineralization of soil nitrogen was enhanced by the flooding and drying treatments both under aerobic and flooded conditions. Also it is evident that nitrification was completely inhibited by these treatments with drying at 60°C and no nitrates could be detected after 4 weeks. Similar results were obtained (Table 6) when the soils were treated with 200 μg NH_4^+-N/g of soil and incubated under aerobic conditions. There was no nitrification in any of the soils subjected to flooding and drying treatments. Luisiana clay however did not show any nitrification of soil or fertilizer N even in the samples without wetting and drying treatments indicating lack of nitrifying activity in this soil during 4 weeks. The lack of nitrification activity in Maahas and Pila soils may be due to drying of soils at 60°C, which might have destroyed the nitrifiers because these are sensitive to temperatures above 45°C[7]. Perhaps ammonifiers could function better even after this repeated wetting and drying of soils. In fact, ammonification of soil as well as fertilizer nitrogen was enhanced by these repeated wetting and drying which resulted in accumulation of higher amounts of NH_4^+-N over control samples. Air drying enhanced the ammonification but retarded the nitrification of the fertilizer NH_4^+ applied after these treatments (Table 7).

Although Luisiana clay soil did not show any nitrification of soil or fertilizer NH_4^+-N with or without wetting and drying treatments, Maahas and Pila clay nitrified at a rapid rate (Table 6) and NO_3^--N formed the major part of the

Table 7. Influence of repeated flooding and drying on mineralization of soil N incubated aerobically at 30°C for 4 weeks

Soil	Pre-treatment	Inorganic N (parts/10^6)		
		NH_4^+-N	NO_3^--N	Total
Maahas clay	Not flooded or dried	29	106	135
Maahas clay	Flooded and air dried	33	88	121
Maahas clay	Flooded and dried at 60°C	76	0	76
Luisiana clay	Not flooded or dried	94	0	94
Luisiana clay	Flooded and air dried	101	0	101
Luisiana clay	Flooded and dried at 60°C	106	0	106
Pila clay	Not flooded or dried	9	97	106
Pila clay	Flooded and air dried	13	72	85
Pila clay	Flooded and dried at 60°C	103	0	103

mineralized nitrogen. Fertilizer N was nitrified to the extent of 72 to 76% of the applied NH_4-N after 4 weeks in these two soils and air drying increased these nitrification rates to 87 to 89% of the applied NH_4^+ during 4 weeks.

It is interesting to note that nitrate formation was completely inhibited by wetting and drying at high temperature treatments and ammonification on the other hand was accelerated. Air drying enhanced both ammonification and nitrification of fertilizer NH_4^+. This may be of consequence for nitrogen losses in soils. These results indicate that nitrification and related N transformation in soils may be altered significantly by repeated flooding and drying. These treatments may curtail soil N losses by nitrification-denitrification but may enhance losses of fertilizer nitrogen.

CONCLUSIONS

The results of this study suggest that alternate flooding and drying of soils may lead to heavy losses of the applied NH_4^+-N due to nitrification-denitrification. Also alternate flooding and drying cycles may stimulate ammonification of soil N but may retard its nitrification. On the other hand both ammonification and nitrification of the fertilizer N seems to have been enhanced by the fluctuating water regimes. Nitrification inhibitors like N-Serve can be useful in minimizing the losses due to nitrification-denitrification reactions.

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