Nitrogen mineralization potential of rice-wheat soils amended with organic manures and crop residues

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Abstract

Mineralization potential (N_0), an estimate of soil organic N that is susceptible to mineralization in infinite time was estimated in 18 samples of soil under rice-wheat system collected from different agroclimatic regions in northwestern India. N_0 ranged from 21.5 to 61.1 mg N/kg soil and was significantly related to organic C and clay content of the soils. A quick (q) reaction was almost completed during 0 to 4 weeks, whereas a slow (s) reaction continued untill the end of incubation period. When 3 soils differing in texture and organic C content were amended with different organic materials, the highest and the lowest values of both N_{0s} and N_{0q} were observed for *Sesbania aculeata* green manure (GM) and wheat straw, respectively. Unlike when applied freshly, the organic amendments did not influence mineralization potential as per their C/N ratio. Amending the soil with different organic manures for 5 or more years enhanced N_0 in the order: farmyard manure (FYM)> GM> poultry manure> press mud (waste from sugar industry). FYM enhanced the mineralization potential to a greater extent than GM (highest N_0 when applied freshly). Application of wide C:N ratio crop residues year after year may increase organic C content of the soil, but not necessarily the potentially mineralizable N. Soil amended with crop residues for 8 years recorded N_{0q} values even less than those for unamended control. When both rice and wheat were amended with crop residues, no rapidly mineralizable fraction of N could be found in the soil.

Media summary

Nitrogen mineralization potential of soils amended with organic materials on short- and long-term basis was investigated to understand reasons for decline in rice yields.

Key Words

Nitrogen mineralization, rice-wheat system, organic manures, crop residues

Introduction

In the Indo-Gangetic Plain of South Asia spread over 12 million ha in India, Pakistan, Nepal, and Bangladesh, rice followed by wheat is the most commonly followed cropping system. With genetic improvements in rice and wheat and improved management strategies a dramatic rise in productivity and production were observed during the eighties. But the system is now showing signs of fatigue and is no longer exhibiting increased production with increases in input use. In the coming decades, a major issue in designing sustainable agricultural system will be the management of soil organic matter and the rational use of organic inputs such as animal manures, crop residues (CR), green manures (GM), sewage sludge and food industry wastes. Among organic manures, farmyard manure (FYM) is the most commonly used manure by the rice-wheat farmers in the Indo-Gangetic plain.

In intensive rice based cropping systems, Olk et al. (1996) have hypothesized a decline in the supplying capacity of N from soil organic matter over time, despite constant or increasing total soil N levels. Olk et al. (1996) also reported that increasing the number of flooded rice crops per year resulted in a more phenolic character of soil organic matter, which may be related to decreased net N mineralization. Indications that soil N supplying capacity may be changing in Asian rice soils comes from on-farm studies which have shown that there is poor correlation between total soil N and N uptake by rice in plots not receiving N fertilizer (Cassman et al., 1996). Similarly, poor correlations between soil organic matter and N uptake in “minus-N” plots in rice - wheat systems have also been reported in Bangladesh and Nepal

(Adhikari et al., 1999). Few studies, however, have examined N mineralization in soils under rice – wheat system.

Methods

Eighteen representative surface (0-15 cm) soil samples were collected from semiarid regions of northwestern India. The incubation leaching technique of Stanford and Smith (1972) was used to study mineralization in the soils. The first estimates of potential N mineralization capacity were obtained by fitting linear regression between 1/Nt and 1/t based on cumulative N mineralized (mg kg^{-1}) during 1, 2, 3, 4, 6, 8 and 12 weeks using the following equation: $1/N_t = 1/N_o + b/t$,where N_t = N mineralized in mg/kg (cumulative) during the specified period of time, t = time in weeks, b = slope, N_o = N mineralization potential (mg N/ kg soil). The hypothesis that the rate of mineralization is proportional to the amount of potentially mineralizable N, is expressed by the equation, dN/dt = -kN (Stevenson, 1965). Integration of this expression gives: $\log(N_o-N_t) = \log N_o - k/2.303(t)$. This equation was employed to arrive at final values of N_o. Finally, the N_o giving the best fit was found by an iterative process involving successive evaluation of $\log(N_o-N_t)$ vs t, by regression analysis, based on different choices of N_o. The values of N_o were those giving the highest value of r^2 for linear fits.

Single and double first order reaction model as described by Inubushi et. al. (1985) was used for computing N_o. For single first order reaction, equation of the form given below was fitted to the experimental data to compute A and B: log (N/ t) = log A – Bt. Values of A and B were used to determine N_o and k for the first order rate equation defined as: $N = N_o$ [1 - exp(kt)] where N_o = A/B ln10 and k = B ln10. The quick reaction was almost completed during 1 to 4 week period whereas the slow reaction continued till the end of incubation. The slow reaction was mathematically formulated from the linear relationship in the later period of incubation. The difference between the amount of mineral N experimentally determined and that calculated from the slow reaction was used for mathematical formulation of the quick reaction. It was found that the quick reaction was another first order reaction. Finally, the following formula was derived: $N = N_{oq}[1-\exp(-k_q t)] + N_{os}[1-\exp(-k_s t)]$, where, N_{oq} and N_{os} are amounts of potentially mineralizable N and k_q and k_s are rate constants for quick and slow reactions, respectively.

Mineralizable N under the influence of long term application of organic manures

Surface soil samples were collected one month after transplanting rice. The incubation-leaching techniques as described above were used to estimate potentially mineralizable N in soil samples collected from plots to which organic amendments such as green manure, farmyard manure, poultry manure, press mud, and crop residues had been applied on long term basis. Respectively, 5 and 6 plots were selected from two long-term experiments in which different organic manures and crop residues have been continuously applied for 5 and 8 years. Mineralization potential following single first order reaction as used by Stanford and Smith (1972) and double first order reaction model as given by Inubishi (1985) were worked out as described above.

Mineralizable N in the soils amended with organic materials on short-term basis

The incubation-leaching technique of Stanford and Smith (1972) was used to estimate kinetics of N mineralization in three soils - - sandy loam, loam and silty clay. These soils were amended with GM, CR, farmyard manure (FYM), press mud (PM) and poultry manure (PLM) at levels commonly applied under field situations in northwestern India. Nitrogen was added at the rate of 300 mg/kg soil in the form of organic manures. The treatments employed were: no N (control), GM, (C/N ratio 12.1), PLM (C/N ratio 14.0), PM (C/N ratio 16.1), FYM (C/N ratio 22.2), and CR (C/N ratio 62.4).

Results

Mineralization potential (Stanford and Smith, 1972), a capacity factor and an estimate of total quantity of soil organic N at time zero that is susceptible to mineralization in infinite time, ranged from 21.5 to 61.1

mg N/kg soil (Table 1) and was significantly related to organic carbon and clay content of the soils. In 8 soils, double first order reaction model for mineralization of N as given by Inubishi (1985) explained the process in a better manner. The two mineralization potentials using this model are described in Table 2. The sum of N_{0q} and N_{0s} always turned out to be more than the N_0 calculated using single first order reaction as used by Stanford and Smith (1972).

The concept of slowly and rapidly mineralizable N potential has proved particularly useful when soils are amended with different types of organic materials on a short- or long-term basis. As shown in Table 2, when three soils differing widely in texture and native organic C content were amended with different organic materials, the mineralization of N was described both by quickly and slowly mineralizable fractions of soil organic matter (Table 3). Values of N_{0s} were conspicuously less than N_{0q} for all the amendments. The highest values of both N_{0s} and N_{0q} were observed for green manure and the lowest values for wheat straw.

Table 1. Nitrogen mineralization potential estimated as per Stanford and Smith (1972) and double first order reaction model of Inubushi et al. (1985) in 18 soils from different agroecological zones in northwestern India

Soil	Textural class	Clay (%)	Org. C (%)	N_0 (mg N/kg soil)		
				Stanford and Smith (1972)	Slowly mineralizable fraction, N_{0q}	Rapidly mineralizable fraction, N_{0s}
1	Silt loam	19	0.65	31.4	29.6	5.8
2	Loam	12	0.50	25.7	-	-
3	Loam	15	0.60	31.7	29.5	15.7
4	Silty clay	48	0.85	39.5	36.1	7.3
5	Silty clay	51	1.05	61.1	54.8	14.1
6	Silt loam	14	0.70	32.0	-	-
7	Silt loam	12	0.40	25.8	-	-
8	Loam	16	0.31	21.5	-	-
9	Loam	26	0.75	39.6	37.0	8.0
10	Loamy sand	13	0.65	32.4	23.8	20.9

11	Sandy loam	20	0.70	38.8	36.1	6.2
12	Sandy loam	18	0.63	31.8	29.6	6.7
13	Loamy sand	11	0.44	27.1	-	-
14	Loamy sand	14	0.60	31.7	29.5	15.2
15	Loamy sand	10	0.55	25.2	-	-
16	Sandy loam	16	0.50	26.6	23.8	12.7
17	Loamy sand	10	0.44	25.9	-	-
18	Loamy sand	11	0.46	24.6	-	-

Table 2. Nitrogen mineralization potential (mg N/kg soil) of slowly (N_{0s}) and rapidly (N_{0q}) mineralizable fractions in three soils amended with different organic manures and crop residues

Organic amendment*	Silty clay soil, pH 7.9, Org. C 1.05 %		Loam soil, pH 8.0, Org. C 0.75 %		Sandy loam soil, pH 8.1, Org. C 0.50%	
	N_{0s}	N_{0q}	N_{0s}	N_{0q}	N_{0s}	N_{0q}
No amendment	37.0	24.3	35.7	11.3	28.0	23.2
Green manure	110.9	53.8	91.2	39.8	70.9	58.3
Poultry manure	87.4	40.6	81.0	40.0	64.6	38.2
Farmyard manure	75.4	-	61.3	24.5	49.6	21.2
Pressmud	87.3	-	71.2	39.8	62.4	25.3
Wheat straw	43.3	20.1	31.8	19.5	36.3	26.2

* Organic amendments were applied @ 300 mg N/kg soil

Effect of organic amendments on mineralization potential of soils is different when these are applied on a long-term basis for several years as in long-term experiments on rice-wheat system. Estimation of mineralization potential in samples of soils taken from different plots of two long-term field experiments to which manures and crop residues have been applied for 5 and 8 years (Table 3) reveal that unlike when applied freshly, the organic amendments do not influence mineralization potential as per their C/N ratio. Amending the soil with different organic manures enhanced N_0 in the order: FYM> green manure> poultry manure> press mud. In case of organic manures, N_{0s} was found to be significantly correlated with organic C content of the soil. A comparison between short-term and long-term amendment of soils with organic manures reveals that FYM can enhance the mineralization potential to a greater extent than green manure, which exhibits the highest N_0 values when applied freshly. Since samples from long-term experiments were taken about one month after application of green manure, it did not affect N_0 as in soils freshly amended with green manure. Application of wide C:N ratio organic materials such as crop residues year after year may increase organic C content of the soil, but not necessarily the potentially mineralizable N. Soil amended with crop residues for 8 years recorded N_{0q} values even less than those for unamended control. Interestingly when both rice and wheat crops were amended with crop residues, no rapidly mineralizable fraction of N could be found in the soil.

Table 3. Effect of long-term application of organic manures and crop residues on nitrogen mineralization potential of the soil under rice-wheat cropping system

Treatment to		N_0 (mg N/kg soil)	
Wheat	Rice	Slowly mineralizable fraction, N_{0S}	Rapidly mineralizable fraction, N_{0q}
No N	No N	17.2	6.3
FYM (200 kg N ha^{-1})	GM (120 kg N/ha)	46.4	21.7
Poultry manure (200 kg N ha^{-1})	GM (120 kg N/ha)	33.9	17.7
FYM (200 kg N ha^{-1})	Poultry manure (200 kg N/ha)	43.2	19.7
Urea (150 kg N ha^{-1})	GM (150 kg N/ha)	28.0	12.8
Urea (90 kg N ha^{-1})	No N	22.9	11.9
Urea (90 kg N ha^{-1})	GM (150 kg N/ha)	28.0	15.2
Urea (90 kg N ha^{-1})	Wheat straw (6t/ha) + GM (150 kg N/ha)	22.8	9.9
Urea (90 kg N ha^{-1}) + rice straw (5 t ha^{-1})	Wheat straw (6t/ha) + Urea (150 kg N/ha)	23.2	-
Urea (90 kg N ha^{-1})	FYM (12 t/ha, fresh)	40.1	17.8

Urea (90 kg N ha^{-1})	FYM (12 t/ha, fresh) + GM (150 kg N/ha)	43.0	23.7

Conclusion

Soils under rice–wheat cropping system in the subtropical semiarid conditions of northwestern India contain part of the organic matter fraction in active form and thus exhibit simultaneously occurring slow and quick N mineralization reaction kinetics. In soils freshly amended with different organic materials, N mineralization potential of the soil was determined by the C/N ratio of the material; low C/N ratio materials such as green manure and poultry manure resulted in higher values than wide C/N ratio materials like farmyard manure. However, farmyard manure rather than green manure can lead to higher N mineralization potential if the soils are amended with organic materials on a long-term basis.

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