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Potentially mineralizable nitrogen in ten important sub-tropical soil series of Bangladesh

Tahmina Sultana[1], Mohammad Mosaraf Hossain[1], Mohammed Abdul Kader*[1, 2, 3]

ABSTRACT

Knowledge on nitrogen (N) supplying capacity of inherent soil organic matter helps farmers and extension workers to determine the N fertilization rate. However, this information is very scanty particularly in developing countries like Bangladesh. Thus, this research work was conducted to estimate potentially mineralizable nitrogen (N) in ten important soil series of Bangladesh namely Jamalpur, Silmondi, Sonatala, Ghatail, Tejgaon, Chandra, Khilgao, Kalma, Brahmaputra and Sherpur. Net N mineralization in these soil series was measured during 100 days laboratory incubation at 20^0C at field capacity. Findings revealed that eight out of ten soil series had silt loam texture and the rest two were loams. All soils were slightly acidic in reaction. The organic carbon and total N contents of the soils varied from 5.24 to 17.4 and 0.53 to1.48 g kg soil^{-1}, respectively with the C:N ratios of 9.89 to 11.76. The amount of net N mineralization and nitrification (NO_3^{-1}-N) increased linearly with time; however, ammonification (NH_4^+-N) did not follow any definite trend. Majority of mineralized N undergone nitrification falling within the ranged between 30 and 128 mg/kg soil/98 days. The net N mineralization (mg NH_4^+-N+NO_3^{-1}-N kg^{-1} soil) varied from 51 mg N kg^{-1} soil in Tejgaon soil series to 154 mg N kg^{-1} soil in Khilgaon soil series accounting for 4.3 to 10.8% of total N mineralized 120 days^{-1}. The rate of N mineralization also varied widely from 1.19 to 0.28 (mg N kg^{-1} soil day^{-1}) like the net N mineralization. The highest rate of N mineralization was observed in Khilgaon soil series followed by Chandra, Ghatail, Silmondi, Sherpur, Jamalpur, Sonatola, Kalma, Bramaputra silt and Tejgaon soil series. N mineralization was significant and positively correlated with organic carbon and total N and NH_4^{+} -N contents of soils. Khilgaon and Chandra soil series have shown greater potentiality in supplying nitrogen under aerobic condition.

Keywords: Nitrogen mineralization, Sub-tropical soil, Nitrification, Ammonification, Soil properties

INTRODUCTION

Management of indigenous soil N is an important issue in soils because N mineralization from soil organic matter provides a substantial portion of the total N taken up by the rice crops. Nitrogen (N) is the most limiting nutrient for crop production in Bangladesh soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield. However, the efficiency of applied N fertilizer in Bangladesh is very low (less than 40%) particularly for rice production (FRG, 2018, Kader *et al.,* 2013, Akter *et al.,* 2018b). Generally, nitrogenous fertilizer recommendations in many rice-growing regions follow a prescriptive approach based on generic models, without considering site-specific differences for crop N requirements, soil series, cropping seasons, application of others organic and inorganic fertilizers etc. (Fan *et al*., 2012; Murthy *et al*., 2015). The mineralization of organic N has to be fully understood and taken into account when meeting the N demand of crops, in order to make more efficient use of mineral N fertilizers. These may reduce the use of chemical fertilizers besides offering better crop return and less environmental degradation. Therefore, an understanding of the relationship between mineralizable N and SOM is essential to accumulate critical experimental evidence across a wide range of soils for use of organic C or total N or other routinely measurable soil properties as an index for determining the N requirement. Extensive numbers of studies have related (potentially) mineralizable N, or its turnover, to soil properties and environmental conditions (Connell *et al*., 1995; Strong *et al*., 1998; Van Eekeren *et al*., 2010, Kader *et al.*, 2013, 2017, Akter *et al.*, 2016, 2018a, 2018b). Soil pH, moisture, and temperature are often nonlinearly related with the dynamics of N (Paul *et al*., 2003). Soil organic matter and its labile fractions are considered important factors in regulating N-dynamics (Ramirez *et al*., 2016; Martinez *et al*., 2017) in view of their key role in N mineralization and N availability to crops. Total N or organic C is used as an index of N supplying capacity of rice soil in many countries of the world particularly in the developing countries (Sahrawat, 2008). In contrast, many reports, especially from intensified rice systems, also showed poor or insignificant relationships between organic C and mineralizable N, yield, or N uptake by wetland rice (Nyiraneza *et al*., 2011, Kader *et al,* 2013). The causes of variability in results on the relationships between SOM and potentially mineralizable N have not been critically evaluated for paddy soil, although information on this aspect could help in developing suitable N management strategies for wetland rice. Therefore, this study was undertaken to estimate release of mineral nitrogen from soil organic matter per cropping season under aerobic soil conditions in ten major soil series of Bangladesh and to study the relationship between routinely measured soil parameters and soil N mineralization.

[1]Department of Soil Science, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh;
[2]School of Agriculture, Geography, Environment, Ocean and Natural Sciences, University of the South Pacific, Samoa;
[3]College of Science, Health, Engineering and Education, Murdoch University, Perth, WA 6150, Australia
*Corresponding Author: mdabdul.kader@usp.ac.fj

MATERIALS AND METHODS

Site description and soil sample collection

Soil samples were collected from 10 major soils series of Jamalpur Sadar upazila of Bangladesh namely Jamalpur, Silmondi, Sonatala, Ghatail, Tejgaon, Chandra, Khilgaon, Kalma, Brahmaputra and Sherpur. Soil samples were collected from15 locations per field by means of an auger from the surface area (0-15 cm). These samples were bulked into one composite sample and were thoroughly mixed. The field moist soils were gently broken apart by hands and the unwanted materials like stones, granules; plant parts, leaved etc. were sorted out and discarded from the samples. The soilswere then air-dried and ground to pass through a 2-mm sieve prior to N mineralization and other studies. Names of the soil series, soil type location and cropping system history of sampled farmers' fields are briefly summarized in Table 1.

Table 1. **Soil series name, soil type, cropping system history of sampled farmers' fields**

Soil ID	Location Village	Soil Series	Soil type	Cropping Pattern
01	Jamalpur Pauroshava	Jamalpur	Aeric Haplaquepts	R-F-R
02	Jamalpur Pauroshava	Silmondi	Aeric Haplaquepts	R-F-R
03	Kendua	Sonatala	Aeric Haplaquepts	M-R-R
04	Meshta	Ghatail	Aeric Haplaquepts	P/M-R-R
05	Hamidpur	Tejgaon	Aquic Ustochrepts	W-J-R
06	Chandra	Chandra	Ultic Albaquepts	R-F-R
07	Sahabajpur	Khilgaon	Typic Haplaquepts	R-R-R
08	Sahabajpur	Kalma	Aeric Haplaquepts	R-R-R
09	Lakshmirchar	Brahmaputra	Typic Fluvaquents	V-V-F
10	Lakshmirchar	Sherpur	Aquic Eutrochrepts	V-V-F

R= Rice, F = Fallow, M = Mustard, P = Potato, V = Vegetable, J = Jute, W = Wheat

Soil texture and chemical analysis

Soil texture was determined by hydrometer method as outlined by Bouyoucos (1927). Soil pH was measured with the help of a glass electrode pH meter using soil water suspension ratio of 1: 2.5 as described by Jackson (1962).Organic carbon of the soil was determined by wet oxidation method as described by Walkey and Black (1934).Total N content in soil was determined by micro-Kjeldhal method. Digestion was made with H_2O_2,conc. H_2SO_4 and a catalyst mixture (K_2SO_4:$CuSO_45H_2O$:Se =100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Page *et al.*, 1982).

Nitrogen mineralization

N mineralization of collected soil were subjected to laboratory incubations aerobically for a period of 14 weeksunder controlled environment conditions at 20℃ by following Kader *et al*. (2013), in order to determine the N mineralization rate. Briefly, 200g soil was placed in a PVC tubes having 5.5 cm inner diameter and 15 cm height. The bulk density of the soil in the tube was adjusted similar to the one in the field by pressing the soil. In total 21(3×7) tubes were taken for each soil for incubation. Soil moisture content was adjusted equivalent to 50% water filled pore space by adding distilled water and it was maintained by monitoring the weight of soil filled incubation tubes every two weeks interval. Every two weeks, soils were sampled destructively by removing the soil from one tube from each replication. The soil was mixed thoroughly and 10 g moist soil was extracted each with 0.01N $CaCl_2$ and 1M KCl [1:50; soil weight (g): extractant volume (ml)] solution for NO_3 and NH_4 measurements, respectively. Soil moisture level was determined at each sampling by oven drying 30 g soil sample.

The $CaCl_2$ extracts were analysed for NO_3-N concentration by spectrophotometer at a wavelength of 210 and 275 nm (Goldman & Jacobs, 1961) as adopted by Kader *et al*., (2013). The NH_4 -N concentration in the KCl extract was measured colorimetrically by indophenol blue method using spectrophotometer at a wavelength of 636 nm (Kemper, 1974). The experiment was only designed to measure the net N mineralization because what is determining for plant productivity is the actual availability of mineral N. Therefore, losses of mineral N by denitrification or N immobilization were not considered, instead, if any fixed-N released during the incubation period was included in calculation of net N mineralization. The N mineralization rates were calculated using zero-order kinetics: $Nt = N_0 + kt$, where t is the time (in days), Nt is the amount of mineral N at time t, N_0 is the initial amount of mineral N ($mgNkg^{-1}$ dry soil), and k is the mineralization rate ($mgNkg^{-1}$ dry soil day^{-1}).

Statistical analysis

N mineralization rate($mgNkg^{-1}$ dry soil day^{-1}) and normalized N mineralization rates(mgN 100g total soil N^{-1}120 day^{-1}) of all collected soil samples were subjected to analysis of variance by using one way ANOVA followed by Duncan's Multiple Range (DMRT) post-hoc test. P values for post-hoc test was set at 5% level of probability. Pearson correlation analysis was done to check the relations between the soil properties and N mineralization rates. All statistical analyses were done using SPSS 19.0 software for Windows (SPSS Inc., USA).

RESULTS

General soil properties

The studied soil series distinctly varied in respect of soil physical and chemical properties. The textural class of the studied soil series varied from loam to silt loam eight of the soil series being silt loam except two namely Tejgaon and Sherpur series being loam. All soil samples were acidic in reaction having pH values ranging between 4.18 and 5.18. The highest value of pH was observed in Jamalpur soil series (5.18) and the lowest value was observed in Tejgaon soil series (4.18). A relatively wide range in organic carbon varied from 5.24 g kg soil^{-1} in Brahmaputra silt to 17.4 g kg soil^{-1} in Kalma soil series. The total N content also followed a wide range like organic carbon. The lowest total N of 0.53 g kg soil^{-1} was measured in Brahmaputra silt while the highest total N content of 1.48 g kg soil^{-1} was measured in Kalma soil series. However, C:N ratio of the studied soil series followed a narrow range between 9.89 to 11.76 which is the typical C:N ratio of arable soils. Initial NO_3^--N and NH_4^+-N contents of soil also varied widely. NO_3^--N varied from 2.7 mg kg soil^{-1} in Tejgaon to 24.95 mg kg soil^{-1} in Sherpur soil series and NH_4^+-N varied from 7.05 mg kg soil^{-1} in Sonatola to 13.5 mg kg soil^{-1} in Khilgaon soil series.

Table 2. Physical and chemical properties of sampled soil series

Soil series	Soil particles (%)			Textural class	P^H	Organic carbon (g kg^{-1})	Total N (g kg^{-1})	C:N ratio (-)	mg kg^{-1}	
	Sand	Silt	Clay						NO_3-N	NH_4^+-N
Jamalpur	13.6	64	22.4	Silt Loam	5.18	10.52	0.94	11.19	5.77	7.87
Silmondi	19.6	58	22.4	Silt Loam	5.06	11.54	1.03	11.20	24.63	8.68
Sonatola	27.6	64	8.40	Silt Loam	5.03	8.5	0.77	11.04	10.75	7.05
Ghatail	19.6	68	12.4	Silt Loam	4.58	11.48	1.03	11.15	10.51	12.32
Tejgaon	33.6	38	28.4	Loam	4.18	7.56	0.67	11.28	2.70	9.55
Chandra	21.6	64	14.4	Silt Loam	4.43	15.02	1.32	11.28	7.43	11.93
Khilgaon	21.6	64	14.4	Silt Loam	4.23	15.89	1.41	11.27	21.64	13.50
Kalma	19.6	64	16.4	Silt Loam	4.55	17.4	1.48	11.76	6.10	10.57
Brahmaputra	21.6	68	10.4	Silt Loam	4.63	5.24	0.53	9.89	11.95	6.66
Sherpur	45.6	44	10.4	Loam	4.73	7.08	0.66	10.73	24.95	6.01

Evolution of NO_3^-–N in soil

The evolution of NO_3^-–N increased mostly linearly with time in all the studied soil series (Figure 1). The Amount of NO_3^-–N evolution ranged between 30 and 128 mgNkg^{-1} soil 98 days^{-1}. The highest value of evolution of NO_3^-–N (mgNkg^{-1} soil)soil was observed in Chandra soil series and the lowest value was observed in Tejgaon soil series. The NO_3^-–N represented 20 to 80% of the total mineral N at the beginning of incubation (Figure 2). The share of NO_3^-–N to total mineral N increased with the advancement of incubation and at the end of incubation, it accounted for 60 to 95% of the total mineral N.

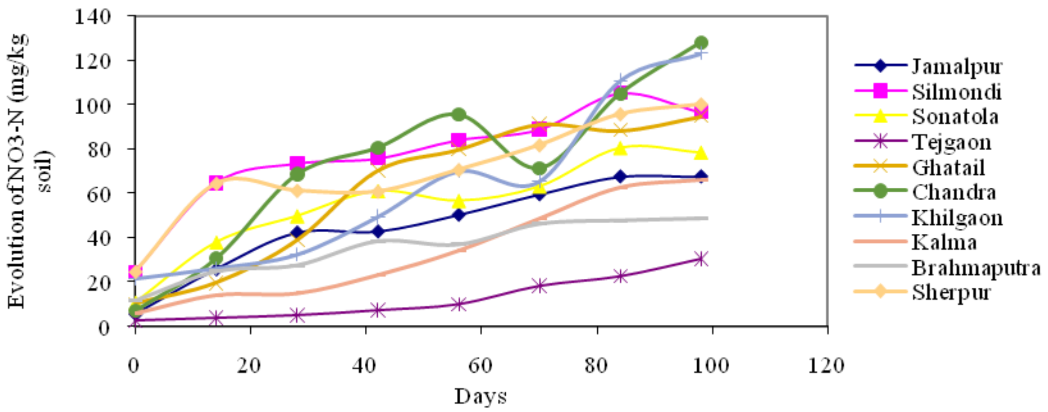

Figure 1. Evolution of NO_3^-–N (mg NO_3^-–N kg^{-1} dry soil) in soils incubated under controlled conditions

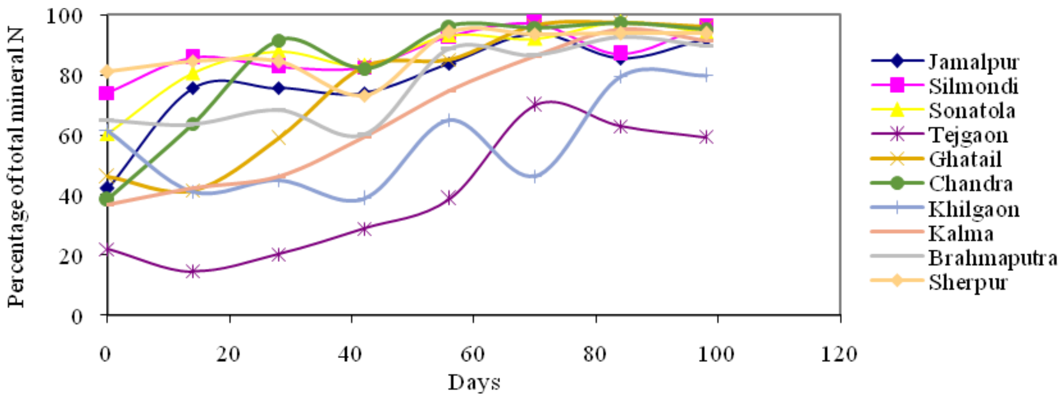

Figure 2. Percentage of evolved NO_3^-–N (mg NO_3^-–N kg^{-1} dry soil) to total soils mineral N (mg NH_4^+–N+NO_3^-–N kg^{-1} dry soil) with time during the incubation period

Evolution of NH_4^+–N in soil

The amounts of NH_4^+–N evolution in all the studied soil series increased until 40 days except Khilgaon soil and thereafter decreased in most of the soil series (Figure 3). In Khilgaon soil, NH_4^+–N evolution did not follow any definite pattern although the NH_4^+–N also decreased at the end of incubation like it did in other studied soil series. There were two highest picks amounting to 79 and 75 mg NH_4^+–N kg^{-1} dry soil at 42 and 70 days of incubation in Khilgaon soil. The amount of NH_4^+–N evolution ranged between 3.8 and 31 mg NH_4^+–N kg^{-1} dry soil except Khilgaon soil series. At the beginning of incubation, NH_4^+–N represented 20 to 80% of the mineral N, however, the share of NH_4^+–N decreased gradually with the advancement of incubation time (Figure 4). At the end of incubation, NH_4^+–N represented only 3 to 7% of the mineral N in most of the soil series except Khilgaon (20%) and Tejgaon (40%) soil series.

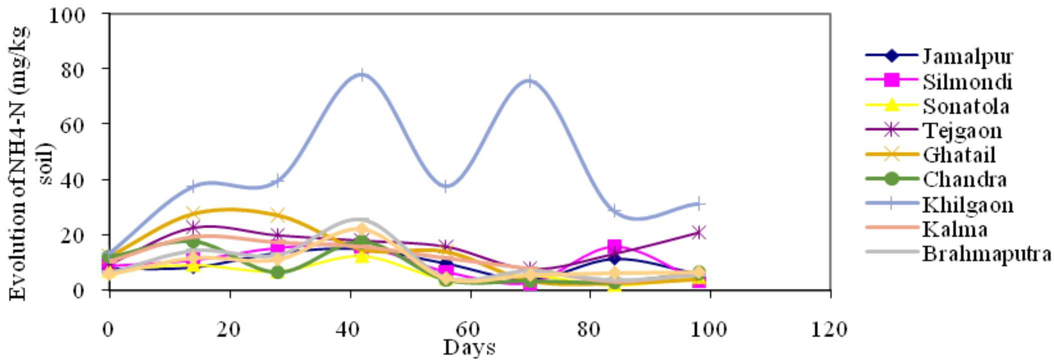

Figure3. Evolution of NH_4^+–N (mg NH_4^+–N kg^{-1} dry soil) in soils incubated under controlled conditions

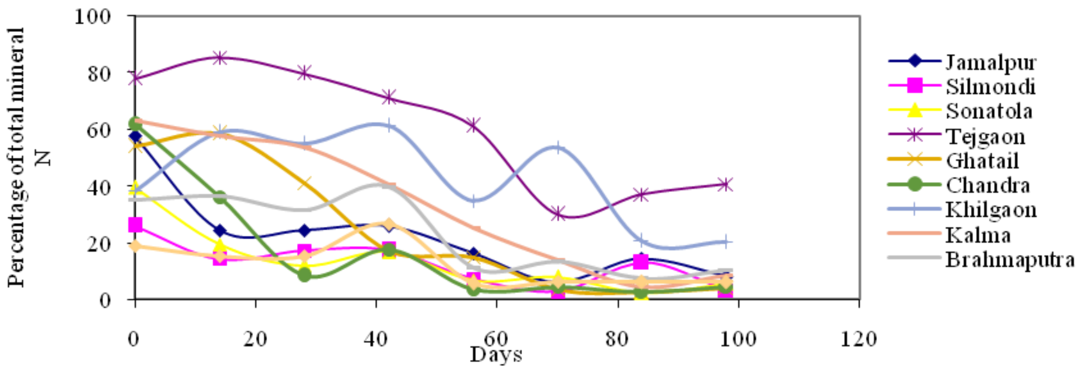

Figure 4. Percentage of evolved NH_4^+–N (mg NH_4^+–N kg^{-1} dry soil) to total soils mineral N (mg NH_4^+–N+NO_3^-–N kg^{-1} dry soil) with time during the incubation period

3.4 Nitrogen mineralization

N mineralization (mg NH_4^+–N+NO_3^-–N kg^{-1} soil) generally increased linearly with time (Figure 5). Therefore, a zero order linear model was fitted to calculate the rate of N mineralization. The amount of N mineralization (mg NH_4^+–N+NO_3^-–N kg^{-1} soil) varied from 51 mg N kg^{-1} soil in Tejgaon soil series to 154 mg N kg^{-1} soil in Khilogaon soil series. The N mineralization rate varied significantly ($P<0.01$) among the soils from 0.28 to 1.19 (mg N kg^{-1} soil day^{-1}) like the net N mineralization. The highest rate of N mineralization was observed in Khilgaon soil series (1.19 mg N kg^{-1} soil day^{-1}) followed by Chandra (0.94 mg N kg^{-1} soil day^{-1}), Ghatail (0.71 mg N kg^{-1} soil day^{-1}), Silmondi (0.59 mg N kg^{-1} soil day^{-1}), Sherpur (0.59 mg N kg^{-1} soil day^{-1}), Jamalpur (0.57 mg N kg^{-1} soil day^{-1}), Sonatola (0.56 mg N kg^{-1} soil day^{-1}), Kalma (0.53 mg N kg^{-1} soil day^{-1}), Bramaputra silt (0.28 mg N kg^{-1} soil day^{-1}) and the lowest in Tejgaon soil series (0.28 mg N kg^{-1} soil day^{-1}) (Table 3). The N mineralization rate of Silmondi, Sherpur, Jamalpur, Sonatola, and Kalma soils were statistically identical. Similarly, N mineralization rate of Bramaputra silt and Tejgaon soil series were statistically identical.

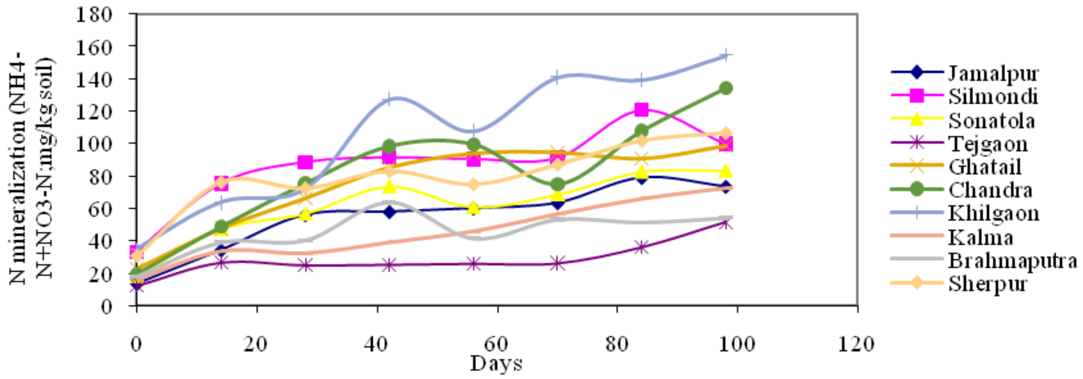

Figure 5. Evolution of mineral N (mg NH_4^+–N+NO_3^-–N kg^{-1} dry soil) in soils incubated under controlled conditions

After extrapolation of the N mineralization for 120 days to represent a rice growing season and normalization with soil total N, the measured N mineralization accounted for 4.3 to 10.8% of total N mineralized 120 days^{-1}. The normalized seasonal N mineralization also varied significantly ($P<0.01$) among the soils. Significantly highest normalized N mineralization was observed in Khilgaon and Sherpur soils and the lowest in Kalma and Tejgaon soils (Table 3).

Table 3. N mineralization and turnover rate of the studied soil series

Soil ID	Soil series	N mineralization	
		(mg N kg soil^{-1} day^{-1})	g N 100g N^{-1} season^{-1} (120d)
1	Jamalpur	0.57±0.10d	7.2±1.2c
2	Silmondi	0.59±0.07d	6.9±0.6cd
3	Sonatola	0.56±0.09d	8.7±1.3b
4	Ghatail	0.71±0.15c	8.3±1.4bc
5	Tejgaon	0.28±0.12e	4.9±1.2e
6	Chandra	0.94±0.16b	8.5±1.7b
7	Khilgaon	1.19±0.02a	10.1±0.8a
8	Kalma	0.53±0.02d	4.3±0.9e
9	Brahmaputra	0.28±0.03e	6.4±0.4d
10	Sherpur	0.59±0.02d	10.8±0.7a

Correlation between N mineralization and general soil properties

Pearson's correlation coefficients between the N mineralization rates and soil organic carbon, total N, C:N ratio, soil pH, initial NO_3^--N, NH_4^+-N, %sand, %silt and %clay contents of soilsare listed in Table 4. Aerobic N mineralization was significant and positively correlated with organic carbon (Figure 6) and total N (Figure 8) contents of soil ($P<0.05$). None of the other soil properties significantly correlated with N mineralization rate. It was observed in Table 4 that some of the soil properties showed inter correlation amongst themselves. For an example, sand content was negatively correlated with soil silt content (*P<0.01*). Soil organic carbon and total N contents showed a significant and positive correlation with C:N ratio and NH_4^+-N content of soil (*P<0.01*).

Table 4. Pearson correlation coefficients (r) between N mineralization rate and general soil properties

Parameters	Sand	Silt	Clay	pH	Organic carbon	Total N	C: N ratio	NH_4^+-N	NO_3^--N
N mineralization rate	-0.21	0.35	-0.25	-0.23	0.69*	0.72*	0.38	0.70*	0.36
Sand		-0.79**	-0.17	-0.23	-0.48	-0.50	-0.22	-0.41	0.32
Silt			-0.48	0.26	0.38	0.41	-0.08	0.29	-0.09
Clay				-0.09	0.07	0.05	0.44	0.13	-0.30
pH					-0.25	-0.25	-0.13	-0.61	0.17
Organic carbon						1.00	0.77**	0.78**	-0.05
Total N							0.74**	0.79**	-0.02
C: N ratio								0.58	-0.24
NH_4^+-N									-0.13

Correlation is significant with ***P* = 0.01 (2-tailed) and **P* = 0.05 (2-tailed).

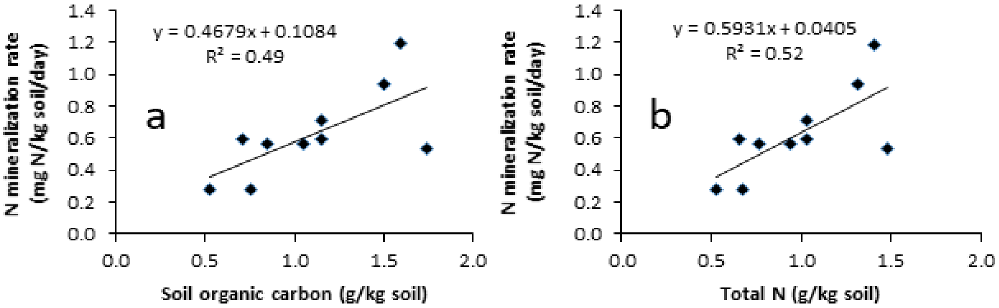

Figure 6.Correlation between N mineralization and soil organic carbon (a) and total N (b)

DISCUSSION

Evolution of NO_3^-–N accounted for the majority of the mineralized N could be due to availability of oxygenated air in the pore space (50% of air-filled pore space) during the whole incubation period. As it is shown in Figure2 that the NO_3^-–N represented 20 to 80% of the total mineral N at the beginning of incubation. The share of NO_3^-–N to total mineral N increased with the advancement of incubation and at the end of incubation it accounted for 60 to 95% of the total mineral N. These linear trends of NO_3^-–N evolution closely match with the NO_3^-–N evolution of a large data set of sub- tropical paddy soils studied by Kader *et al*., (2013). On the other hand, the amounts of NH_4^+–N evolution in all the studied soil series increased until 40 days except Khilgaon soil and thereafter decreased in most of the soil series (Figure 3). This decrease in NH_4^+–N after 40 days of incubation could be due to immobilization of some of the released NH_4^+–N by soil microbes as the losses of released NH_4^+–N through volatilization could have been minimum due to the aerobic moisture conditions (50% of water filled pore space) maintained throughout the incubation period. This rate of N mineralization in the studied soils fall within the range of N mineralization of 0.08 to 1.86 mg N kg^{-1} day^{-1} reported by Kader *et al*. (2013) for a set of subtropical paddy soils. After extrapolation of the N mineralization for 120 days to represent a rice growing season, the measured N mineralization accounted for 4.3 to 10.8% of total N mineralized 120 $days^{-1}$. The relative N mineralization within 120 days growing season was in the range of previously measured N mineralization of 2.5 to 15% of the total soil N 120 $days^{-1}$ for a set of Bangladeshi paddy soils by Kader *et al*. (2013); 4.0 to 9.4% of total N 120 $days^{-1}$ and 3.1 to 10.6 % of total N 112 $days^{-1}$ by Li *et al*. (2011) for Chinese paddy soils. However, the present rate of N mineralization is relatively higher compared to previously measured N mineralization of 1 to 5% of total N 112 $days^{-1}$ by Manguiat *et al*. (1996) for paddy soils sampled from four Asian rice growing countries (Philippines, Indonesia, Malaysia, and Thailand). Significantly positive correlation between N mineralization and soil organic carbon (*P<0.01*) and total N (*P<0.01*) contentis logical particularly under aerobic condition. Total soil N supply N to microbes for mineralization while soil organic C supply C to microbes for obtaining their energy as most of the microbes involved in aerobic N mineralization are heterotrophs. This correlation is in line with Kader *et al*., (2013). They also did not find any correlation between other soil properties and N mineralization rate. Such positive correlations between N mineralization and SOC and N contents have also been reported by many others (Sahrawat 1984a, b; Narteh and Sahrawat, 1997; Sahrawat and

Narteh, 2001) who observed very strong positive correlations between N mineralization and SOC and N contents.

CONCLUSION

Nitrogen supplying capacity under aerobic condition, among the soil series, Khilgaon and Chandrahave shown very high potentiality. Ghatail, Silmondi, Sherpur, Jamalpur, Sonatola, Kalma soil series can be graded as having the medium potentiality in N supplying capacity while Brahmaputra silt and Tejgaon soil series ranked very poor.

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