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Nitrogen mineralization potential in sludge amended soils

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Abstract

An incubation study was done to study nitrogen mineralization potential of sludge amended soils. Three type of soils i.e. alluvial red and black soil wereused, sludges were mixed with soils at the rates of 0, 25 and 50 g sludge kg^{-1} soil (dry weights). It was observed that total mineralized nitrogen increased with increasing the period of incubation. The mineralized nitrogen content initially higher in black soil as compare to red and alluvial soil, but in latter stages the total mineralized nitrogen content is highest in alluvial soil. The mineraliseable nitrogen content increased with the increase in amount of sludge application. The mineralization of nitrogen was greatly affected by the soil type. In black soil i.e. high clay content soil having slow rate of mineralization which highest for alluvial soil and the rate is highest for alluvial soil and intermediate in red soil. First order model of kinetics of nitrogen mineralization was best suited for nitrogen mineralization. The estimated rate constant for black soil, red soil and alluvial soil was 0.42, 0.89, and 1.05 respectively having correlation coefficient (r^2) 0.99.

Key words- Mineralization, nitrogen, first order reaction, sludge

Introduction

Nitrogen is an essential macro element for plant growth and yield. Crop plants are highly susceptible to nitrogen deficiency that causes drastic reduction in yield and quality. So nitrogen availability is an important factor for successful crop production. Excessive use of chemical fertilizer causes depletion of organic matter from the soil. Addition of organic waste such as sewage sludge has been proposed as one method of maintaining levels of organic matter in agricultural soils (Gracia *et al.*, 1992 and Boyle and Paul, 1989).

In addition, land application of appropriately treated organic waste has frequently been demonstrated to be a safe and effective means for recovery of plant nutrients while simultaneously improving soil physical and microbiological properties. However, the application rate of sewage sludge to land must be determined on the basis of crop N requirement to avoid potential hazards associated with excessive NO_3^- in soil (Paul and Clark, 1989). Sludge is the semi solid part of the domestic and industrial wastes that has been sedimented or acted upon bacterial. Sludge contains 3% N, 2% P_2O_5 and 0.5% K_2O (Biswas and Mukherjee, 1990). In India, total 50 million cubic meters of untreated sewage is discharged each year and combined; the 22 largest cities in the country produce over 7,267 million litres of domestic wastewater per day, of which slightly over 80 per cent is collected for treatment. Annual production of solid waste in India has been estimated to be 2,000 million tones. In spite of their low nutrient content they can supplement use of chemical fertilizer because of their huge production potential. Mineralization of the organic N in sludge is a complex process affected by several factors such as soil type, soil pH, temperature, moisture and rate and type of sludge. Different authors have indicated that mineralization kinetics vary according to the type of sewage sludge stabilization process, aerobic or anaerobic. Stanford and Smith (1972) estimated the N mineralization potential N_0 and rate constant (k) of the kinetic equation to be first order, using a model based on a logarithmic function. This model was improved by Smith *et al.* (1980) who found that a non-linear least-squares equation gave more accurate estimations of K and N_0. Different studies have been conducted on the influence of sludge characteristics on potential N mineralization N_0 but studies on the influence of soil type on potential sludge N mineralization in freshly amended soils are scarce. Information on N mineralization in various soil-organic systems is needed for a better prediction of crop N requirements. The objectives of this study to determine the influence of soil type and sludge application rate on the rate and extent of N mineralization in soils freshly amended with sludgeand to estimate values for N_0, k and mineralization rate by the Smith *et al.* (1980) method.

Materials and methods

For this study surface layer (0–15 cm) samples of three soils of three different order were collected from three different places in Utter Pradesh; black soil from Shahanshahpur (Vertisoil, Silty Clay Loam textured), red soil from Barkachha (Alfisoil, Sandy Loam) and alluvial soil from Varanasi (Inceptisoil, Sandy Loam). Anaerobically digested sludge from a municipal sewage treatment plant at Bhagwanpur near Banaras Hindu University was used in this study. Sludge was taken from sludge drying beds. Sludgewas mixed with soils at the rates of 0, 25 and 50 g sludge kg^{-1} soil (dry weights). Amended and control soils were placed in plastic pots for incubation in a controlled incubation chamber (BOD incubator). The samples were incubated aerobically under a non-leached procedure for 20

weeks at 25°C. The soil moisture content was maintained at field capacity. Mineralized nitrogen, NO_3^- - N and NH_4^+- N was determined at the starting of the experiment and after 4, 8, 12, 16 and 20 weeks of incubation.

Chemical analysis

Mineralized N in soils and sledges was determined by a semi-micro-Kjeldahl method (Bremner, 1965a); NH_4^+ –N was measured in the 2 M KCl extract (1/10 w/v) by Kjeldahl distillation method; NO_3^- –N was determined in the K_2SO_4 extract (1/3 w/v) by ion selective electrode method and heavy metal was determined by Atomic absorption spectrophotometer (UNICAM SOLAAR 969) using DTPA extract. To evaluate the potential availability of the organic N of sludges a non-linear regression mathematical model proposed by Smith *et al.* (1980) was used. The proposedequation is the following:

$$N_m = N_0 (1 - e^{-kt})$$

Where, N_m is the amount of N mineralised associated with sludge at a specific time (t); N_0 is the potentially mineralisable organic nitrogen; k is the first-order rate constant; t is the time of incubation. In this development, N_m (net N mineralised) is the sum of the inorganic forms of the N in soil for each treatment adjusted for mineralisation of soil N and the initial inorganic N added in the sludge. Data were analyses using the analysis of variance for a completely random design. Comparisons between means were made using Duncan's multiple range test.The statistical analysis system computer language was used to calculate N_0 and k.

Results and discussion

Nitrogen mineralization in sludge amended soil

From the observed data (Table.1) total nitrogen mineralized after four week of incubation period in black soil 295 mg/ kg soil. It is increased to 356.5 mg/kg soil after eight week of incubation which is about 20.80%, more than the 4 week of incubation. Nitrogen mineralized after 12 weeks of incubation period was 442.7 mg/kg soil. It is about 24.18% more nitrogen mineralized than previous observation. After 16 Week of incubation only 4.18% increase in mineralized nitrogen content is observed, because due to long time incubation cause several losses of nitrogen predominant. But after that there is stabilization of nitrogen mineralization occurs.

The cumulative mineralized nitrogen content increased with the increase in sludge application rate. The observed results show that sludge application increases the mineralised nitrogen content over time. The mineralization becomes slows down with time. So, less amount of nitrogen mineralized after 12 week of incubation. Higher mineralization rate during early period of incubation and decreasing rate with time have

also been reported by Lindemann and Cardenas (1984). The flush of mineral nitrogen and corresponding high mineralisation rates during the initial period of incubation were attributed due to the decomposition of very labile organic nitrogen. As the first pool (more labile organic nitrogen) disappears the second pool of organic nitrogen predominates which is somewhat resistant to further decomposition and contributes a small proportion of nitrogen mineralisation during a short-term incubation .Total nitrogen mineralized after 4 Week of incubation period in red soil 99 – 112.5 mg/kg soil. It increased to 120.9 mg/kg after 8 week of incubation period that is about 22% more than the previous observation. Nitrogen mineralized after 12 Week of incubation period was 159.4 mg/kg, which is about 61% more than 4 Week observation. Mineralised nitrogen content does not increase significantly with the sludge amendment. At 4 weeks of incubation the available nitrogen content increases about 9% and 13.6% by the application of 50 ton ha^{-1} and 100 ton ha^{-1} respectively but after 20 weeks of incubation available nitrogen content does not increase to this level. The cumulative nitrogen content increases after 20 weeks of incubation from initial period about 294.1% in control red soil, where as 237% and 239.1% with the application of 50 ton ha^{-1} and 100 ton ha^{-1} of sludge respectively. This value shows that higher sludge application rate does not increase available nitrogen content. This phenomenon occurs due to lack of organic matter in red soil. So addition of higher amount of sludge causes immobilization of nitrogen and this phenomenon increases with time.

Table 1: Cumulative mineralized nitrogen (mg Kg^{-1} soil) in sludge amended soil

Treatment	Incubation Period (Week)				
	4 Week	8 Week	12 Week	16 Week	20 Week
Black soil	295.0	356.5	442.7	461.2	530.2
Black soil + sludge @ 50 ton/ha	413.7	562.8	700.7	773.9	841.4
Black soil + sludge @ 100 ton/ha	775.0	1114.5	1236.5	1314.9	1376.2
Red soil	99.0	120.9	159.4	210.9	390.2
Red soil + sludge @ 50 ton/ha	108.0	181.2	231.7	280.9	364.0
Red soil + sludge @100 ton/ha	112.5	186.5	234.7	321.5	381.5
Alluvial soil	59.9	269.5	275.8	367.9	846.0
Alluvial soil + sludge @50 ton/ha	116.7	157.2	271.7	456.0	1132.9
Alluvial soil + sludge @ 100 ton/ha	176.0	380.0	686.3	1118.2	1812.5
Sludge (100%)	4626.6	4953.3	5971.0	14040.7	14437.3

The total nitrogen mineralized after 4 week of incubation was 59.9 mg/kg in alluvial soil .The nitrogen mineralized after 8 weeks of incubation period was 269.5 mg/kg soil. After 12 weeks of incubation, slight increase in mineralized nitrogen at 12 weeks of incubation. It may be due to losses and immobilization of nitrogen. At latter period, there is rapid increase in mineralized nitrogen. Mineralized nitrogen content increased with sludge content. In sludge sample there is a sequential increase in mineralised nitrogen over time.Higher mineralisation rate during early period of incubation and decreasing rate with time have also been reported by Lindemann and Cardenas (1984). The flush of mineral nitrogen and corresponding high mineralisation rates during the initial period of incubation were attributed due to the decomposition of very labile organic nitrogen. As the first pool (more labile organic nitrogen) disappears the second pool of organic nitrogen predominates which is somewhat resistant to further decomposition and contributes a small proportion of nitrogen mineralization during a short-term incubation.

The addition of sludge increased significantly the soil mineralisable N content the increases being directly related to the application rate and sludge N content. Soil mineralisable -N content tended to decrease with the incubation time, particularly during the first four Weeks of incubation. Since the incubation was carried out under a non-leached procedure, this decrease in Kjeldahl-N content could be attributed to gaseous losses of N due to ammonia volatilization or to denitrification processes. The losses of mineralisable nitrogen during the 20-week incubation time were higher in the amended black soil (higher clay content) than alluvial and red soil, suggesting the influence of soil type on sludge organic matter mineralization. Other researchers (Lindeman and Cardenas, 1984; Chae and Tabatabai, 1986) also found that the total N mineralized in sludge-treated soils varied markedly, depending on the type of soil used. Stevenson (1986) indicated that soil clay content influences organic matter mineralization, clay protecting organic matter from mineralization. The application of sewage sludge increased only slightly the content of ammonium–N in soil. A general increase of ammonium–N with time was observed in all treatments but differences between soils or treatments were not relevant. In sole sludge (100%), the nitrogen mineralization rate was almost constant up to 12 weeks of incubation, after that there was a rapid increase in mineralized nitrogen content at 16 weeks of incubation period, then a steady mineralization was continued. Sludge contain high amount of organic carbon, which causes immobilization of nitrogen at initial period of incubation. So, mineral sable nitrogen content was less in the initial period of incubation. At latter a stage as the carbon content was decreased the mineral sable nitrogen content increases. After 16 weeks of incubation the carbon and nitrogen content (C:N ratio) become stabilized and a constant mineralization rate was obtained.

The incorporation of sludge into the soils resulted in an immediate increase in inorganic nitrogen. These increases were due to the N added to the soil in the form of sludge, the anaerobic sludge richer in N (Table. 1), producing the highest inorganic N

increases in all soils. In all cases the content of inorganic nitrogen increased with the incubation time. However, the differences among the amended and unamended soils were more noticeable in the black soil. No difference due to the application rate was observed with regard to the inorganic N content of the amended soils or its evolution with the incubation time. This was in agreement with the finding of Lindeman and Cardenas (1984) who in leaching incubation experiments of sludge-amended soils observed that doubling the sludge rate did not double the cumulative inorganic N leached. After 20 Weeks of incubation the amended soils accumulated much more inorganic nitrogen (NO_3^--N and NH_4^+- N) than the unamended soils, this confirming the fertilizing value of sludge.

The rate of N mineralization (mg kg^{-1} $Week^{-1}$) decreased with time. Mineralization rates were greatest during the first two Weeks of incubation. Thereafter the rates decreased slowly for the rest of the experiment. Higher mineralization rates was observed in the early weeks of incubation and a decreased rate with time. This was attributed to the initial decomposition of the very labile organic N. As more labile organic N disappeared and more recalcitrant organic N predominated in the organic N pool, the rate of mineralization would be expected to become lower. N mineralization in the unamended red and alluvial soil was very small due to its low organic matter and N content.

Mineralization of sludge organic N was calculated by subtracting the amount of N mineralized in the unamended soil from N mineralized in the sludge-treated soil. This approach assumes that sludge addition did not improve mineralization of soil organic N (priming effect). Although N mineralization from soil organic matter has been found to be affected by sludge application. This former assumption is generally accepted in studies of N mineralization of organic wastes (Parker and Sommer, 1983 and Chae and Tabatabai, 1986). Net mineralization values (Nm) for sludges in each soil (calculated by subtracting the initial inorganic N soil content and that mineralized in unamended soil from the increases in inorganic N during the incubation. The patterns and amount of N mineralized from the sludges studied varied depending on the type of soil to which the sludge was added. For soil + sludge mineralization: a rapid release of nitrate in the first two Weeks followed by a slower N release over the incubation period. However, in the black soil there was an increase of N in the first eight weeks of incubation after which slight changes in N values was observed. In this soil, the anaerobic sludge, when applied at the high rate showed a particular pattern: inorganic N content increased only after eight weeks of incubation and then remained nearly constant over the remaining incubation period. The first four weeks the N levels were under those at the starting point, which could suggest that immobilization processes had taken place. Several investigators have reported that sludge application to soil resulted in N immobilization during the initial phase of sludge decomposition. However, in this case, sludge organic N decreased during this four Weeks incubation time in all treated-soils. This led us to think that the inorganic N losses observed from the start to four weeks of incubation in the treated-soil, were not due to N

immobilization processes but to N loses by ammonia volatilization or by denitrification processes. In all soils the higher sludge application rate yielded lower cumulative inorganic N than the low application rate.

Kinetics of nitrogen mineralization in sludge amended soil

A nonlinear least square (NLLS) regression was used to calculate 'No' and rate constant (k) from the 20 Weeks data. The NLLS method was used to reduce the error imposed by the logarithmic transformation value of mineralization data (Smith *et al.,* 1980).

Table 2-Nitrogen mineralization rate constant (k) and half life ($t^{1/2}$) for sludge amended soils

Types of soil	K(Week^{-1})	$t^{1/2}$	r^2
Black soil	0.42	1.65	0.99
Red soil	0.89	0.78	0.99
Alluvial soil	1.05	0.66	0.99
Sludge	0.58	1.19	0.99

The correlation coefficient (r^2), half life and rate constant (k) was obtained for sludge organic N mineralization by using the Smith *et al*. (1980) model are presented in Table: 2.Thek values obtained ranged from 0.42 to 1.05 week^{-1}. These values were higher than those reported by Chae and Tabatabai (1986) and Lindeman and Cardenas (1984) but similar to those reported by Serna and Pomares (1992) and Parker and Sommer (1983). There was a good agreement between actual and predicted N mineralization values. Data obtained for the all soil at the high anaerobic sludge rate application did not obey the model proposed by Smith *et al.* (1980) at later stages of incubation. Because this model was proposed for mineralization of soil N, not for substrate N, this lack of fit is probably not surprising. Chae and Tabatabai (1986) in incubation experiments with different soils amended with different type of organic materials found that data obtained for soil amended with certain sludges, animal manures or plant materials did not obey the Smith et al., model, while results for other treated soils readily fitted this model.

Conclusion

Total mineralized nitrogen increased withincreasing the period of incubation, mineralized nitrogen content was initially higher in black soil as compared to red and alluvial soil, but in latter stages the total mineralized nitrogen content was highest in alluvial soil. The mineralizable N content increased with the increase in amount of sludge application. The mineralization of nitrogen was greatly affected by the soil type. In black

soil i.e. high clay content soil having slow rate of mineralization which highest for alluvial soil and the rate was highest for alluvial soil and intermediate in red soil. First order model of kinetics of nitrogen mineralization was best suited for nitrogen mineralization.

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