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SOIL SCIENCE

Kinetics of nitrogen mineralization in sewage amended soil

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Abstract

A laboratory experiment was carried out at, Jaunpur (25°18' N, 83°03' S) to study the kinetics of N mineralization in sewage amended soils. Four different agricultural fields viz., A, B, C and D which has been receiving sewage for irrigation since last five or more years were selected for study. The three replicate of each treatment were incubated at room temperature (25°C) for 7 weeks. The soils were brought to field capacity by addition of distilled water. The subsamples (10g) were withdrawn from each sample after every week interval and extracted immediately with 100 ml of 2 M KC1 solution and N was determined. The fitness of the model for mineralization study was tested by least square method and the mineralization rate constant (K) and half-life ($t^{1/2}$) were calculated from fitted model. It was observed that, the highest mineralized N (121.20 mg/kg) was observed in soil receiving sewage continuously while lowest in N mineralized 112.80 mg/kg was observed in soil receiving less amount of sewage. Estimated mineralization rate content 'K' in four soils was 0.44, 0.38, 0.10 and 0.43 and correlation coefficient were 0.99, 0.98, 0.99 and 0.99, respectively. The study revealed that, nitrogen mineralization was increased with increasing period of incubation with rapid increase during 2-4 weeks of incubation. First order model of kinetics was best suited for nitrogen mineralization in sewage amended soil under study.

Highlights

- Nitrogen mineralization in sewage amended soil increases with increasing period of incubation
- The highest nitrogen mineralization occurs during 2-4 weeks of incubation.
- Nitrogen mineralization in sewage amended soil follows first order model of kinetics.

Keywords: Nitrogen mineralization, kinetics, sewage amendment, first order model

Sewage is the liquid by product of domestic and industrial wastes. Sludge is the semi – solid part of sewage water that has been sedimented or acted upon by bacteria thus, it is a residual product from the treatment of municipal wastewater (Linden *et al*., 1995) containing 40-60% organic matter (Ross *et al*., 1991). Organic matter is the food source for soil microorganisms and serves as a slow-release nutrient source for plants. Slowed decomposition hinders the release of essential nutrients and results in a nutrient sink. Sewage sludge has been used frequently as an organic amendment for soils (Clapp *et al*., 1986; Alabaster and Leblanc, 2008; Rovira *et al.*, 2011). The safe disposal of the sewage sludge is one of the major environmental concerns throughout the world. Disposal alternatives that have been tried include soil application, dumping at sea, landfilling and incineration (Sanchez Monedero *et al*., 2004). Landfilling and land application of the sewage sludge are suggested to be the most economical sludge disposal methods (Metcalf and Eddy, 2003; Roig *et al*., 2012) as it contains essential plant nutrients, primarily Nitrogen and Phosphorus (Carrington *et al*., 1998a; 1998b; Marschner *et al*., 2003; Singh and Agrawal, 2008; Annabi *et al*., 2011). The micronutrients i.e. Fe, Cu and Zn plays an important role in plant growth which get absorbed more in sludge-amended soil than those grown in the control soil (Hernandez *et al*., 1991). The organic matter in sludge is a key component to its success as an organic amendment (Clapp *et al*., 1986; Marschner *et al*., 2003) which acts as a beneficial soil conditioning agent (Logan and Harrison, 1995; Singh and Agrawal, 2008). Besides organic matter and macronutrients sewage sludge also contains a wide range of micronutrients, non-essential trace metals, organic micro pollutants and microorganisms (Kulling, 2001; Smith, 2009; Passuello *et al.,* 2010) whereas the benefits of input of sludge on soil properties found to be proportionally to the application doses and/or frequency. The organic amendments increased the organic matter content, the soil nitrogen, and improving carbon and nitrogen mineralization processes through microbial activities in soil (Roig *et al.,* 2012)

Nitrogen is of particular interest because it is usually the most limiting nutrient for plant growth (Pierzynski *et al*., 2000; Benbi and Richter, 2002; Gilmour *et al*., 2003). Nitrogen is present in sludge as both organic N (N-org) and NH_4–N, the amounts depending on the method of sewage and sludge treatment (Boyle, 1990; Smith, 1996; Smith *et al*., 1992). Nitrogen in liquid raw sludge is largely in the organic form, with only 5–10% being NH_4–N. Mineralization of organic N results in the formation of NH_4–N, which then is converted to nitrate by the process of nitrification. Mineralization rates are dependent on three factors that will affect microbial activity: temperature, moisture content, and substrate quality (Sparrow *et al*., 1993; Crohn, 2004). Assimilation of NH_4–N costs less metabolic energy than assimilatory reduction of NO_3- N for plants and microbes (Recous *et al*., 1990; Schlesinger, 1997; Gilmour *et al*., 2003). Microbial consumption of $NO_3{}^{2-}$-N can be significant under high C availability (Stark and Hart, 1997; Burger and Jackson, 2003) and is strongly influenced by microbial substrate use efficiency (Saetre and Stark, 2005). The rate of mineralization is required to predict or estimate N availability during the growing season and can vary with the source of organic matter (Serna and Pomares, 1992; Crohn, 2004) but relatively little known about the mineralization of nitrogen in sewage amended soil especially ultisols. Therefore, laboratory experiment was conducted to study the nitrogen mineralization in sewage amended soil.

Materials and Methods

A laboratory experiment was conducted at Department of Agriculture Chemistry and Soil Science, Purvanchal University, Jaunpur (25°18′ N, 83°03′ S) to study the kinetics of N mineralization in sewage amended soils. Geographically, Jaunpur district falls under subtropical belt with MSL 128.93 meter. The atmospheric temperature varies widely ranging from 6°C or even low during winter season and 48°C during summer, most of the rainfall is received during middle of July to end of August. Four different agricultural fields viz. A, B, C and D which has been receiving sewage for irrigation since last five or more years were selected for study. Representative soil samples (0-15 cm) were collected from the field; the collected soil samples were air dried, ground to pass through a 2 mm sieve and preserved in the plastic bags for further study. Initial physical and chemical properties of soil viz. bulk density, particle density, porosity (Klute *et al*., 1986), pH (1:2 soil water suspension), electrical conductivity (1:2 soil: water suspension using digital conductivity meter), organic carbon (Walkley and Black, 1934), available N (Subbiah and Asija, 1956), available P (Olsen *et al*., 1954) and available K (Hanway and Hiedel, 1952) were determined using standard methods.

Table.1. Physico-chemical properties of soil

Sr. No.	Soil Properties	Values
1	Bulk density (Mg m^{-3})	1.30
2	Particle density (Mg m^{-3})	3.01
3	Soil porosity (%)	53.00
4	pH	7.76
5	EC (dS M^{-1})	0.57
6	Organic carbon (g kg^{-1})	5.20
7	Available nitrogen (kg h^{-1})	420.00
8	Available potassium (kg h^{-1})	162.00
9	Available phosphorus (kg h^{-1})	12.00

Table. 2. Cumulative amount of N mineralized in four soils (mg kg^{-1}).

Incubation period (weeks)	N mineralized in soil (mgkg^{-1})			
	A	B	C	D
1	19.30	13.40	19.00	18.00
2	37.30	25.00	43.60	33.60
3	77.60	42.80	71.20	62.90
4	103.35	62.00	102.60	81.90
5	115.60	81.40	109.70	104.10
6	117.50	91.90	111.50	107.00
7	121.20	112.80	115.30	113.00

Incubation

The soil samples from each treatment (replicated three times) were brought to field capacity by adding distilled water and incubated at 25°C (room temperature) for 7 weeks. The N was extracted immediately with 100 ml of 2M KCl solution from subsamples (withdrawn from each sample after regular 7 days interval) and determined by Kjedahl method. (Bremner and Mulvaney, 1982).

Kinetics of N mineralization

The values of N_o and K were estimated using first order kinetics equation. First order kinetics for N mineralization can be expressed by the equation:

$$\text{Log}\,(N_o\text{-Nm}) = \log N_o - (K/2.303) \times t$$

Where,

N_o = Initial amount of mineralized N,

Nm = Amount of N mineralized at t time and

K = Mineralization rate constant.

The fitness of the model for mineralization study was tested by least square method (Elhance and Elhance, 1990). The mineralization rate content (K) and half-life ($t^{1/2}$) were calculated from fitted model.

To determine both No and K, it is necessary to estimate the initial substrate concentration or potentially mineralizable nitrogen (No) by using experimental data from an incubation. No was derived from the regression analysis of 1/Nm Vs 1/t in which the reciprocal of intercept gave value of N mineralization potential (No). Using this estimate of No regression log (No-Nm) on 't' the value of K was determined. The half-life time for time N mineralization ($t^{1/2}$) was derived from the relationship $t^{1/2} = 0.693/k$ (Stanford and Smith, 1972).

Results and Discussion

Initial Physico-chemical properties of experimental soil

The experimental soil was neutral, having medium organic carbon, medium nitrogen, low potassium and phosphorous (Table. 1)

Nitrogen mineralization

The amounts of mineralized N differed significantly in all four soils at each incubation period (Table 2). The total N mineralized after one week in 'A' soil was 19.30 mg/kg. It increased to 37.30 mg/kg after 2 week of incubation period, which is just double of N mineralized in first week. N mineralized after third week of incubation period was 77.60 mg/kg. It was 52% more than N mineralized in previous observation. After 4 weeks of incubation experiment N mineralized was 103.35 mg/kg, which is 34 more than third week of incubation. After 5 weeks of incubation only 19% increase in N mineralization was observed. It was due to less organic matter available for N mineralization. N mineralized after 6 and 7 weeks of incubation period was 117.50 and 121.20 mg/kg, respectively. Very little N mineralization was reported in last two weeks. From the above result, it was found that large amount of mineralized N were observed during 2 to 4 weeks of incubation period. Higher mineralization rates during early period of incubation and decreasing rate with time have also been reported earlier (Lindemann and Cardenas, 1984). Mohanty *et al* (2013) reported that the amount of N released per unit C mineralization was higher in aerobic system that may result in greater loss of N from the system.

The flush of mineral N and corresponding high mineralization rates during the initial period of incubation were attributed due to the decomposition of very labile organic N. As the first pool (more labile organic N) disappears the second pool of organic N predominates which is somewhat resistant to further decomposition and contributes a small proportion of nitrogen mineralization during a short-term incubation (Stanford, 1968). First order decay rates assumed in yearly time scale decomposition of organic matter for release of C and N in soils Manzoni and Porporato, 2009).

The total N mineralization after one week of incubation period in B soil 13.40 mg/kg (Table 2). The cumulative amount of N mineralized in B soil was depicted in Figure 2. It increased to 25 mg/kg after 2 weeks of incubation period, which is approximate; two-time more than N mineralized in first week. N mineralized after third week of incubation period was 42 mg/kg. It was observed that 40% more than N mineralized than pervious observation. After 4 weeks of incubation experiment N mineralized was 62 mg/kg, which is 32% more than third observation. After 5 week of incubation only 23% increase in N mineralized was observed. It was due to lack of organic matter of N mineralization. N mineralized after 6 and 7 weeks of incubation period was 91.90 and 112.80 mg/kg respectively. In last two weeks of incubation period, very low N mineralization takes place compared with 2 to 4 weeks of incubation period.

The total N mineralized after one was 19.00 mg/kg in C soil (Table 2). The cumulative amount of N mineralized in C soil was depicted in Figure 3. The N mineralized after 2 weeks of incubation period was 43.60 mg/kg which was 56% more than N mineralized in first week. N mineralized after third week of incubation period was 71.20 mg/kg, which was 40% more than N mineralization in second observation. After 4 weeks of incubation, N mineralized was 102.60 mg/kg, which is 30% more than third incubation. Only 7% increase in N mineralization after five weeks of incubation was observed. It was due to low organic matter available for N mineralization. N mineralized after 6 and 7 weeks of incubation period was 111.50 and 115.30 mg/kg respectively.

From the Table 2, it is clear that, the total N mineralized after one week in D soil was 18.00 mg/kg. It increased to 33.60 mg/kg after two weeks of incubation period, which is just double of N mineralized in first week. N mineralized after third weeks, of incubation period was 62.90 mg/kg. It was 47% more than N mineralized in second. After fourth weeks of incubation period N mineralized was 81.90 mg/kg, which is 23% more than third incubation.

After 5 weeks of incubation period was 104.1 mg/kg N mineralized. It is 22% more than fourth incubation. N mineralized after 6 and 7 weeks of incubation period was 107.0 and 133.0 mg/kg, respectively. It was due to less organic matter and microbial activity for N mineralization. From the above results of was found that large amounts of mineralized N were obtained during 2 to 4 weeks of incubation period.

Higher mineralization rates during early period of incubation and decreasing rate with time have already been reported (Lindemann and cardenas, 1984). Kamkar *et al.* (2014) revealed that the maximum release of N was significantly correlated with nature of organic matter and period of decomposition. The flush of mineral N corresponding high mineralization rates during the initial period of incubation were attributed to decomposition of very labile organic N. As first pool (more labile organic N) disappears, the second pool organic N predominates

Table. 3. N-Mineralization rate constant (K), correlation coefficient (r^2) and half-life ($t^{1/2}$) for different soil.

Kinetics Equation	Soil 'A'			Soil 'B'			Soil 'C'			Soil 'D'		
	K	r^2	$t^{1/2}$	K	r^2	$t^{1/2}$	K	r^2	$t^{1/2}$	K	r^2	$t^{1/2}$
Zero order	2.02	0.9	0.34	2.25	0.9	0.3	2.03	0.9	0.34	2.49	0.9	0.28
First	0.44	1	1.58	0.38	1	1.8	0.1	1	0.68	0.43	1	1.6

K- $(week)^{-1}$ and $t^{1/2}$ in weeks

which somewhat resistant to further decomposition and contributes a small proportion of nitrogen mineralization during a short-term incubation (Stanford, 1968; Gilmour and Mauromoustakos, 2011).

The cumulative mineralized N followed the sequence: A Soil > C Soil > D Soil > B Soil. The maximum nitrogen mineralized during seven weeks of incubation was observation in A Soil, while lowest N mineralized was observed in B Soil.

Kinetics of nitrogen mineralization

A nonlinear least square (NLLS) regression analysis was used to calculate number and rate constant from the 7 weeks data. The NLLS method was used to reduce the error imposed by the logarithmic transformation of low value mineralization data (Smith *et al.*, 1980). The correlation coefficient (r^2) half-life ($t^{1/2}$) and rate constant (K) was presented in Table 3.

Nitrogen mineralization rate constant (K), correlation coefficient (r^2) and half-life ($t^{1/2}$) estimated by zero order model were 2.02, 0.91 and 0.34 and by first order model were 0.44, 0.99 and 1.58, respectively.

Since correlation coefficient of first order model of N mineralization is higher than zero models therefore, first order model is best suited for N mineralization study.

N mineralization rate constant (K), correlation coefficient (r^2) and half-life ($t^{1/2}$) in Table 3 estimated by zero order model were 2.25, 0.92 and 0.30 and estimated by first order model were 0.38, 0.98 and 1.80, respectively.

Since correlation coefficient (r^2) of first order model of N mineralization is higher than zero models, therefore, first order model is best suited for nitrogen mineralization study.

N mineralization rate constant (K), correlation coefficient (r^2) and half-life ($t^{1/2}$) in Table 3 estimated by zero order model were 2.03, 0.93 and 0.34 and estimated by first order model were 0.10, 0.99 and 0.68, respectively.

Correlation coefficient (r^2) of first order model of N mineralization is higher than zero models, therefore, first order model is best suited for N mineralization study.

In the Table 3, it was shown that the N mineralization rate constant (K), correlation coefficient (r^2) and half-life ($t^{1/2}$) estimated by zero order and first order model were 2.49, 0.94 and 0.28, respectively, and 0.43, 0.99 and 1.60 respectively. Higher 'K' value in all sewage-amended soil could be mainly due to large percentage of readily mineralization N present in soils treated freshly with sewage.

Since, correlation coefficient (r^2) of first order model of N mineralization is higher than zero models, therefore, first order model is best suited for N mineralization study.

The results of Roig *et al.* (2012) showed that the input of sludge enhances soil properties proportionally to the application doses and/or frequency. The organic amendments increased the organic matter content, the soil nitrogen, and improving nitrogen mineralization processes Soni *et al* (1994); Haney *et al* (2008); Cartes *et al* (2009) and Noe (2011) reported similar results.

Conclusion

The study revealed that, the nitrogen mineralization in sewage amended soil was increased with increasing period of incubation with rapid increase during 2-4 weeks of incubation. First order model of kinetics was best suited for nitrogen mineralization in sewage amended soil.

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