Communications in Soil Science and Plant Analysis, 36: 1681–1689, 2005

ISSN 0010-3624 print/1532-2416 online
DOI: 10.1081/CSS-200059116

Nitrogen Mineralization Under Saline Conditions

M. Irshad, T. Honna, and S. Yamamoto
Laboratory of Soil Science, Faculty of Agriculture, Tottori University
Koyama-cho, Tottori City, Japan

A. E. Eneji
Arid Land Research Center, Hamasaka-cho, Tottori City, Japan

N. Yamasaki
Laboratory of Soil Science, Faculty of Agriculture, Tottori University
Koyama-cho, Tottori City, Japan

Abstract: The conversion of soil nitrogen (N) from its organic into inorganic forms has been the subject of several investigations, but information on N mineralization in saline soil is scanty. The study was therefore carried out to observe trends in N mineralization in saline soils amended with manure and urea. The electrical conductivity (ECe) of saline soils was 0.2 (S0), 4.1 (S1), and 11.4 dSm^{-1} (S2). The N sources were applied at the rate of 300 $kg\,N\,ha^{-1}$ and incubated for 8 weeks at 25°C. The pattern of N mineralization was a function of both soil salinity and N sources. The amount of NH_4-N released was significantly higher in S0 than S1 or S2, especially in urea treated soils. The NH_4-N release varied in the order of urea > manure > control with a peak period of release at the 4th week of incubation. Nitrification of NH_4-N to NO_3-N was reduced by salinity treatments. Patterns of NO_3-N release during incubation were opposite that of NH_4-N. Total mineralized N was highest in the urea treatment. Manure application increased ECe of soil by 18%.

Keywords: Incubation, manure, N mineralization, salinity, urea

Received 12 April 2004, Accepted 23 September 2004
Address correspondence to M. Irshad, Laboratory of Soil Science, Faculty of Agriculture, Tottori University Koyama-cho, Tottori City 680-8553, Japan. E-mail: mirshad67@yahoo.com

INTRODUCTION

Nitrogen (N) applied to soil in organic and inorganic forms may be used by plants, lost from the soil-plant system, or immobilized by soil microorganisms and gradually transformed into stable forms. The decomposition and nutrient release of organic wastes applied in soils are greatly influenced by abiotic and biotic factors. Several studies have shown significant correlations between the initial chemical composition of organic residues and mineralization rate (Palm and Sanchez 1991). The magnitude of these transformations varies widely according to the experimental conditions. Nitrogen is a limiting factor in saline-sodic soils, and application of N fertilizers increases the crop growth up to a moderate level of salinity (Ravikovitch and Yoles 1971), but use of excessive fertilizers or fertilization in highly saline-sodic soils is agronomically unsound. The efficiency of N fertilizer in salt-affected soils depends upon the nature and amount of fertilizer added, its mineralization characteristics with time, rate of gaseous losses, soil type, and degree of soil salinity (Gandhi and Paliwal 1976). Eneji et al. (2002) also reported that N mineralization was a function of both soil and manure types. The evaluation of nitrogen transformation under saline condition is desirable to enhance its use efficiency in saline soils. However, such studies are few and poorly documented.

Salts that may occur in or are applied to soils in various operations have a significant influence on N availability to agronomic crops. Gandhi and Paliwal (1976) reported that inhibition of nitrification was directly related to the amounts of salts applied to the soil. Different results have been reported regarding ammonification. Some investigators noted an increase (Agarwal Singh, and Kanehiro 1971), whereas others observed a decrease (Laura 1977) with increasing salinity. These conflicting results, coupled with the limited knowledge of mineralization of manure N in saline soils suggest a need for a detailed study. The objectives of this research were to (1) determine the magnitude of NH_4-N and NO_3-N release from N sources under saline conditions, and (2) determine the changes in soil pH and EC during incubation as affected by the interaction of salinity and N sources.

MATERIALS AND METHODS

The selected properties of soil and composted manure used are given in Table 1. The soil samples were air-dried and screened via a 2-mm sieve. A subsample to be used as an untreated control (nonsaline or S0 EC_e:0.2 dSm^{-1}) was reserved. Two levels of saline soils were prepared from other subsamples by adding mixtures of $CaCl_2$, NaCl, and $NaHCO_3$ salts at the rate of 80 and 160 mmolc L^{-1}, respectively. The ratio of Na:Ca in the solution was 2:1 on molar basis. The ECe of the saline soils achieved were 4.1 and 11.4 dSm^{-1} denoted as S1 and S2, respectively. The pH (saturation paste) of salinized soil was 6.2 for S1 and 6.5 for S2. Soil

Table 1. Chemical analysis of soil and manure used for incubation study[a]

Property	Unit	Soil	Manure
Textural class	—	Loamy sand	—
Total N	g kg^{-1}	0.2	25.7
Total C	g kg^{-1}	3.0	242.7
C/N ratio	—	—	9.4
NH_4-N	mg kg^{-1}	6.4	34.4
NO_3-N	mg kg^{-1}	4.8	1606
Exch. Ca	$cmol_{(+)}$ kg^{-1}	0.7	9.5
Exch. Mg	$cmol_{(+)}$ kg^{-1}	0.7	16.5
Exch. Na	$cmol_{(+)}$ kg^{-1}	0.1	39.5
Exch. K	$cmol_{(+)}$ kg^{-1}	0.1	156.4
pH H_2O (1:5)	—	6.1	8.3
EC (1:5)	dSm^{-1}	0.1	11.7

[a]The values are on an air-dry basis.

samples (S0, S1, and S2) were treated with two sources of N: composted cattle manure and urea, and there was a control. Air-dried manure was collected from the cattle feedlot yard of Tottori University. Nitrogenous material was mixed with soil (500 g each) having three levels of salinity at a rate of 300 kg N ha^{-1} (based on 2 million kg soil per plow layer) to provide a total of nine treatment combinations. All treatments were in duplicate. Urea was dissolved in a known volume of water and added to the soil to achieve the above N rate, whereas the manure was mixed with the soil in milled form. The dry weight of manure (equivalent to above N level) applied to soil samples was 3.0 g. One hundred mL water was added to each soil sample and mixed thoroughly.

The soil samples of 500 g (on an air-dry basis) were placed in polythene bags with tops loosely folded to allow aeration. The samples were stored in an incubating room at 25°C for 8 weeks. Occasionally the moisture content was maintained by weighing and adding necessary distilled water to incubating samples. Samples for the determination of NH_4-N and NO_3-N were collected at week 1, 4, and 8. Ammonium and NO_3-N were extracted from the samples with 2 *M* KCl (1:5 soil/KCl volume), and concentrations were determined colorimetrically using a spectrophotometer (model U-2001, Hitachi Corp., Japan) at 635 and 410 nm, respectively. Sample pH was measured in the soil-KCl slurry during extraction. Electrical conductivity of 1:5 (soil:water) suspension was also measured. Results of all determinations were expressed on an oven-dry soil (105°C) basis. Data were statistically analyzed using StatView software. Where differences between treatments were significant, means were separated using the LSD with the P-level set at 5% confidence level.

RESULTS

Ammonification

The trend in NH_4-N level varied with the level of salinity and source of N (Table 2). Ammonium-N level in nonsaline soil (S0) was higher than that in S1 or S2 in both manure and urea treatments. The interactive effect of salinity and N sources was significant as shown in the analysis of variance (Table 3). Across the salinity levels, ammonification varied in this order: urea > manure > control. During the incubation period, a marked increase in NH_4-N level was noted at the 4th week. Thereafter, the level decreased regardless of salinity level.

Nitrification

The pattern of NO_3-N release (Table 4) during incubation differed widely among levels of soil salinity and type of N source applied. Nitrate production was higher in S0 as compared to S1 and S2. The higher level of NO_3-N was obtained in manure, and the lowest was in urea treatments. Under normal soil, nitrification was slightly enhanced in the unamended soils (Table 4) but was

Table 2. Ammonium release (mg kg^{-1}) as affected by N source and level of salinity

		Week			
Nitrogen source	Salinity level	1	4	8	Mean
Control	S0	8.38	7.73	4.91	7.01
	S1	5.19	7.82	6.11	6.37
	S2	6.01	8.61	6.26	6.96
	Mean	6.52	8.05	5.76	
	LSD(0.05)	0.69			
Manure	S0	7.02	12.36	10.51	9.96
	S1	6.82	10.43	8.59	8.61
	S2	6.86	10.42	9.40	8.89
	Mean	6.90	11.07	9.50	
	LSD(0.05)	1.21			
Urea	S0	67.02	181.69	163.58	137.43
	S1	67.77	138.62	139.32	115.23
	S2	39.04	132.48	144.88	105.46
	Mean	57.94	150.93	149.26	
	LSD(0.05)	13.08			

*For this and subsequent tables: S0 = normal soil (ECe = 0.2 dSm^{-1}); S1 = 4.1, and S2 = 11.4 dSm^{-1}.

Table 3. Summary of analysis of variance of the influence of N source and salinity on N mineralization, EC, and pH of soil

Source of variation	NH_4-N	NO_3-N	Total inorg. N	EC	pH
			F-values		
Salinity (S)	17.33[a]	65.08[a]	38.94[a]	1806.64[a]	175.91[a]
N source (N)	2203.25[a]	13.16[a]	2031.19[a]	18.04[a]	46.08[a]
Week (W)	181.83[a]	58.97[a]	199.19[a]	18.11[a]	60.10[a]
S × N	15.19[a]	NS	14.41[a]	NS	7.63[a]
S × W	3.32[a]	3.35[a]	NS	4.20[a]	14.62[a]
N × W	160.79[a]	4.14[a]	153.13[a]	NS	7.04[a]
S × N × W	3.48[a]	4.51[a]	4.31[a]	NS	7.24[a]

[a]Denotes the level of significance ($p < 0.05$); NS: nonsignificant.

retarded in saline soils. During incubation, NO_3-N mineralization increased at the 8th week of measurement in both urea and manure-treated soils. Under manure treatment, NO_3-N fell markedly during week 4 due to microbial immobilization and again increased at week 8. There was an insignificant interaction between salinity and N source as shown in Table 3.

Total mineralized-N (TMN [Σ NH_4-N + NO_3-N]) for urea-treated soils was much higher than manure treatment. Generally an increase in TMN

Table 4. Nitrate release (mg kg^{-1}) as affected by N source and level of salinity during 8 weeks of incubation

Nitrogen source	Salinity level	Week 1	Week 4	Week 8	Mean
Control	S0	9.92	8.83	16.13	11.62
	S1	5.01	8.10	8.96	7.35
	S2	5.26	6.26	10.49	7.33
	Mean	6.73	7.73	11.86	
	LSD(0.05)	1.67			
Manure	S0	10.87	8.15	21.13	13.38
	S1	6.34	3.53	10.96	6.96
	S2	6.35	4.21	7.98	6.18
	Mean	7.85	5.30	13.35	
	LSD(0.05)	1.88			
Urea	S0	7.01	10.63	10.85	9.50
	S1	4.03	3.02	10.48	5.84
	S2	4.81	2.22	4.80	3.94
	Mean	5.28	5.29	8.71	
	LSD(0.05)	2.56			

Table 5. Release of total inorganic N (mg kg^{-1}) as affected by N source and level of salinity during 8 weeks of incubation

		Week			
Nitrogen source	Salinity level	1	4	8	Mean
Control	S0	18.31	16.12	21.04	18.49
	S1	10.20	15.92	15.07	13.73
	S2	11.27	14.88	16.75	14.30
	Mean	13.26	15.64	17.62	
	LSD(0.05)	1.47			
Manure	S0	17.90	20.51	31.64	23.35
	S1	13.16	13.96	19.55	15.56
	S2	13.22	14.64	17.38	15.08
	Mean	14.76	16.37	22.85	
	LSD(0.05)	1.55			
Urea	S0	74.02	192.32	174.45	146.93
	S1	71.80	141.64	149.80	121.08
	S2	43.86	134.70	149.65	109.40
	Mean	63.22	156.22	157.96	
	LSD(0.05)	13.24			

was observed during the incubation (Table 5). Under salt treatments, the average mineralized N differed in the order of S0 > S1 > S2. Irrespective of salt treatments, the lowest value of mineralized N was found in the 1st week and was highest in the 8th week of incubation.

Electrical Conductivity (EC) and pH

The electrical conductivity was markedly increased following manure/urea application, with the highest value occurring in the manure treatment (Table 6). During incubation, the EC value was highest in week 8. The magnitude of change in pH was also influenced by salinity and manure treatments. Manure application significantly increased soil pH during incubation (Table 6). The pH of the saline soil was also increased as a result of $NaHCO_3$ salt addition. The pH was significantly higher in urea and manure-treated soils as compared to control.

DISCUSSION

Excess of soluble salts in soil may reduce not only the osmotic potential of soil and nutrient solution or cause specific ion toxicity in plants but may also affect

Table 6. Electrical conductivity (EC) and pH of soil as affected by N source and level of salinity during 8 weeks of incubation

	EC (dSm^{-1})	pH
Salinity level		
S0	6.34	4.58
S1	42.37	5.22
S2	113.60	5.63
N source		
Control	48.88	4.83
Manure	59.76	5.25
Urea	53.67	5.34
Week		
1	50.40	4.97
4	51.54	5.05
8	60.38	4.96
LSD (0.05)	3.72	0.11

the soil microflora. As shown in the previous results, mineralization of organic N to NH_4-N (ammonification) was affected by type of N source and level of salts. There was about 16% decrease in NH_4-N in S1 and 23% in S2 as compared to S0 in urea treatment. The trend observed for ammonification contrasted with that of nitrification among the N-sources. For urea, a greater release of NH_4-N was recorded during incubation. Laura (1974) reported no inhibition of ammonification in soil even at 5.1% salts level, but later findings (Laura 1977) showed that increasing salinity progressively retarded ammonification without suppressing it completely.

The observed decrease in nitrification with increasing salinity during our study was possibly due to adverse osmotic effects on autotrophic nitrifiers. Gandhi and Paliwal (1976) have documented a retardation of nitrification with increased salinity. Several authors have also reported that nitrifying bacteria were sensitive to such conditions as low pH, high salinity, and drought (Focht and Verstraete 1977; Laura 1977). As nitrification is a biological oxidation of NH_4^+, the low level of NO_3 observed at certain stages during incubation of the amended soils could also be explained by insufficient aeration or microbial immobilization, as the activity of nitrifiers in soil is limited by the concentrations of NH_4 and O_2. As cited by Eneji et al. (2002), at low oxygen concentrations the autotrophic nitrifiers were poorer competitors for oxygen than heterotrophic bacteria. The low amount of NO_3-N noted in manure, especially in week 4, could relate to multiplication of microorganisms that may have resulted in immobilization and denitrification. Apparently, salinity had more detrimental effects on the nitrification process than ammonification. Sindhu and Cornfield (1967) reported that heterotrophic organisms responsible for ammonification in soil were comparatively more tolerant to salinity than nitrifiers. Manure use led to a slightly increased level of mineralized N as compared to control. However, for both saline and nonsaline soils treated with manure, N mineralization was low. The pattern of total inorganic N production (Table 5) was similar to that observed for NH_4-N among all salinity levels. This was because NH_4-N was the dominant form of inorganic N throughout the incubation period. Evidence presented here indicated that the soil containing the same amount of salts differed in the release of NO_3- plus NH_4-N. The possible mechanisms of mineral-N losses from the saline soils could include the denitrification of accumulated NO_3-N, the immobilization of accumulated NO_3-N or NH_4-N, and volatilization of NH_4-N. The lower values of mineralized N showed that manure would have been subjected to some N mineralization during composting or storage and N losses during incubation. The decrease in the NH_4-N after the 4th week could be attributed to nitrification or immobilization. The results also showed that inorganic-N in saline soil was relatively less than in nonsaline soil during the incubation period. This could suggest that addition of salt also suppressed the native N mineralization process.

The increases in EC level with manure and/or urea application could be due to the addition of salts from the manure. Earlier results obtained by Eneji, Honna, and Yamamoto (2001) have also shown an increase in EC of soils following manure amendments. Chang, Sommerfeldt, and Entz (1990) found that manure application increased the total soluble salts and Na adsorption ratio in the soil. The pH of the manured soils was generally higher than the control. However, after an initial increase in pH of soils, there was a slight decrease with increasing time of incubation. Changes in soil pH during incubation following manure + urea amendments have been documented by Eneji et al. (2002). Changes in pH following urea application was affected by soil type, duration of incubation, soil moisture, temperature, and urease enzyme activity (Paramasivam and Alva 1997). The initial increase in the soil pH following urea application was due to hydrolysis of urea into ammonium carbonate through the action of urease enzyme (Rowell 1994). The pH was subsequently decreased in the treated soils due to the production of nitrate through nitrification. Similarly, changes in pH following the application of urea to soil have been reported by several authors (Gameh, Angle, and Axley 1990, Wang and Alva 1996).

In conclusion, N mineralization was dependent on N sources and level of soil salinity. The availability of nitrogen from its organic sources to plants could be retarded under saline conditions. This study could help explain our earlier observation of low nitrogen uptake by maize grown under saline conditions following urea and manure application (Irshad et al. 2002).

ACKNOWLEDGMENTS

The authors are grateful to the Japan Society for the Promotion of Science (JSPS) for supporting the continuation of this research through the first author.

REFERENCES

Agarwal, A.S., Singh, B.R., and Kanehiro, Y. (1971) Ionic effect of salts on mineral nitrogen release in an allophanic soil. *Soil Sci. Soc. Am. Proc.*, 35: 454–457.

Chang, C., Sommerfeldt, T.G., and Entz, T. (1990) Rates of soil chemical changes with eleven annual applications of cattle feedlot manure. *Can. J. Soil Sci.*, 70: 673–681.

Eneji, A.E., Honna, T., and Yamamoto, S. (2001) Manuring effect on rice grain yield and extractable trace elements in soils. *J. Plant Nutr.*, 24 (7): 967–977.

Eneji, A.E., Honna, T., Yamamoto, S., Saito, T., and Masuda, T. (2002) Nitrogen transformation in four Japanese soils following manure + urea amendment. *Commun. Soil Sci. Plant Anal.*, 33 (1&2): 53–66.

Focht, D.D. and Verstraete, W. (1977) Biochemical ecology of nitrification and denitrification. *Adv. Microbial Ecol.*, 1: 135–214.

Gameh, M.A., Angle, J.S., and Axley, J.H. (1990) Effects of urea-potassium and nitrogen transformations on ammonia volatilization from urea. *Soil Sci. Soc. Am. J.*, 54: 1768–1772.

Gandhi, A.P. and Paliwal, K.V. (1976) Mineralization and gaseous losses of nitrogen from urea and ammonium sulphate in salt affected soils. *Plant Soil.*, 45: 247–255.

Irshad, M., Yamamoto, S., Eneji, A.E., Honna, T., and Endo, T. (2002) Urea and manure effect on growth and mineral contents of maize under saline conditions. *J. Plant Nutr.*, 25 (1): 189–200.

Laura, R.D. (1974) Effects of neutral salts on carbon and nitrogen mineralization of organic matter in soil. *Plant Soil.*, 41: 113–127.

Laura, R.D. (1977) Salinity and nitrogen mineralization in soil. *Soil Biol. Biochem.*, 9: 333–336.

Palm, C.A. and Sanchez, P.A. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem.*, 23: 83–88.

Paramasivam, S. and Alva, A.K. (1997) Leaching of nitrogen forms from control-released fertilizers. *Commun. Soil Sci. Plant Anal.*, 28 (17&18): 1663–1674.

Ravikovitch, S. and Yoles, D. (1971) The influence of phosphorus and nitrogen on millet and clover growing in soil affected by salinity. II. Plant composition. *Plant Soil.*, 35: 555–567.

Rowell, G.L. (1994) *Singapore Soil Science: Methods and Applications*; Singapore Publishers: Singapore, 350pp.

Sindhu, M.A. and Cornfield, A.H. (1967) Comparative effect of varying levels of chlorides and sulphates of sodium, potassium, calcium and magnesium on ammonification and nitrification during incubation of soil. *Plant Soil.*, 27: 468–472.

Wang, F.L. and Alva, A.K. (1996) Leaching nitrogen from readily soluble and slow release fertilizers in sandy soils. *Soil Sci. Soc. Am. J.*, 60: 1454–1458.