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Carbon and Nitrogen Mineralization of a Plant Residue Amended Soil: The Effect of Salinity Stress

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Abstract

A factorial combination of saline and non-saline soil with three residue types (*Sesbania grandiflora, Caliandra calothyrsus* and *Gliricidia maculata* leaves) was used in laboratory incubation. The CO_2-C content of plant residue amended soils was found to be increased steadily during the first two weeks of incubation followed by gradual reduction as incubation progressed. Under non-saline condition (*EC*=0.97 dS/m), the highest cumulative CO_2-C content (1551 mg/kg soil) was observed in *Caliandra* amended soil, followed by *Sesbania* (1161 mg/kg soil) and *Gliricidia* (1042 mg/kg soil). The higher biodegradability of *Caliandra* leaves induced by the higher C content compared to the other residues. The CO_2-C evolved under saline condition (*EC*=18.2 dS/m), ranged from 313 mg/kg (control) to 905 CO_2-C mg/kg (*Caliandra* amended) soils. *Sesbania* amended non-saline soil showed the highest (227 mg/kg soil) and rapid release of NH_4^+-N, followed by *Gliricidi*a (181 mg/kg soil) and *Caliandra* (177 mg/kg soil). Whereas under saline condition, release of NH_4^+-N ranged from 93 mg/kg (control) to 183 mg/kg (*Sesbani*a amended). Though treatment behavior pattern of NO_3^- -N was similar to that of NH_4^+-N throughout the incubation, saline soil showed significantly ($P \leq 0.05$) low NH_4^+-N and NO_3^- -N contents compared to non-saline soil.

Key words: Soil quality, Plant residues, Carbon and nitrogen mineralization, Salinity stres

Introduction

Soil salinity, one of the key contributors to land degradation (Al Yassin, 2005), exits in topographically low lands near the sea where intrusion of seawater to the aquifer is inevitable and in irrigated agricultural fields (Okur, 2002). The salt caused both by natural and cultural effects on soil can be of chemical, physical and biological origin (Okur, 2002). The affected saline soils are characterized by high concentrations of soluble salts and low organic matter and nitrogen content (Asmalodhi *et al.,* 2009). As it provides unfavorable condition for plant growth resulting in poor crop yield (Anjum *et al.,* 2005), reclamation is needed to ensure sustained crop production in these affected soils. Reclamation or improvement of these soils can basically be accomplished in many ways, the best dictated by local conditions and available resources (Elsharawy *et al.*, 2008).

As the negative effects of salinisation are intensified by the low levels of soil organic matter (Muhammad *et al.,* 2005), addition of organic materials was found to be a sound strategy for reclamation of these soils (Garcia, 2000). Different organic materials such as plant residues, animal manure or sewage sludge are being used as soil amendments and a source of nutrients for improving the soil quality. Despite plant residues can influence soil organic matter depending on their quantity and biodegradability (Dick and Gregorich, 2004), mineralization of nutrients from the added organic amendments can widely be varied (Rowell *et al.*, 2001; Nakhone and Tabatabai, 2008). Salinisation has been identified as one of the most stressing environmental conditions for soil microorganisms (Sardinha *et al.,* 2003), thus nutrient mineralization of such soil could be affected by the high concentrations of soluble salts. Moreover, release of inorganic forms of N, P and other organically-bound nutrients in soil is functionally associated with carbon mineralization (Mafongoya *et al.,* 2000) hence, is affected by the salinity stress that inhibits the mineralization of organic materials in soil. The effects of biochemical composition of organic amendments on their decomposition kinetics have extensively been investigated (Thuriès *et al.,* 2002). Moreover, several microbiological studies such as soil respiration and microbial biomass under saline conditions have also been reported (Okur, 2002). However, interaction between plant residue quality and salinity affecting carbon and nitrogen mineralization/immobilization is not well understood (Nourbakhsh and Hossein, 2006). The effects of salinity on soil biological processes often showed contradictory results (Vanessa *et al.,*

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2004). Therefore, the objectives of this study were to investigate the effects of salinity on carbon and nitrogen mineralization of a plant residue amended soil.

Materials and Methods

Soil characteristics and sampling

Soil samples were collected in February, 2009 from randomly selected several locations along the coastal belt of the Madiha East GS Division of Matara, Southern Sri Lanka to represent saline soils. Non-saline soil samples were also collected from the same GS Division, but approximately 1000 m away from the sea. After removing the surface litter, soil samples were taken from 0 - 15 cm depth of the soil profile using an auger. They were transported to the laboratory in poly bags and stored at 4°C prior to analysis. Analytically grade chemicals without further purification were used throughout the experiment. The soil used in this study belongs to Red Yellow Podzolic great soil group and is classified as Hapludults according to the USDA soil taxonomy (Mapa *et al.*, 1999). The physico-chemical characteristics of the soil were determined prior to the incubation using standard methods (Table I). A digital pH meter (model 868) was

Table I: Initial physico-chemical properties of saline and non-saline soil of the experimental field

Property	Non saline soil	Saline soil
Soil texture	Sand - 84 % Silt - 12 % Clay - 04 %	Sand - 81 % Silt - 08 % Clay - 11 %
Bulk density (g/cm^3)	1.23	1.25
Soil pH	6.3	8.04
EC (dS/m)	18.2	0.97
Organic C (%)	1.06	0.9
Total N (%)	0.13	0.3
Borax P (mg/kg of soil)	96.3	230
Exchangeable K (mg/kg of soil)	175	110

used in measuring soil pH and EC readings were measured in suspension of H_2O (1:2) by conductivity meter (CC-317). Micro Kjeldhal method (McGill and Figueiredo, 1990) was applied to measure total nitrogen content and soil P was extracted according to borax method (Dick and Tabatabai, 1977) and determined using a spectrophotometer (UV - 2102). Exchangeable K (Blackmore *et al.,* 1987) was determined using an atomic absorption spectrophotometer (PGENERAL, TAS-986) and wet oxidation method (Tiessen and Moir, 1993) was applied to determine soil organic matter content. Soil texture was determined with the Sedimentation and Decantation method. All the chemicals were analytically graded and used without further purification. De-ionized water taken from a Millipore Milli-Q system was used throughout the experiments. All measurements of weight were performed with a digital balance (Sartorins, BS 210 S). The experiment was conducted at the Department of Soil Science, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka.

Plant residue characteristics

Fully matured healthy leaves of *Sesbania grandiflora, Caliandra calothyrsus* and *Gliricidia maculata* were collected from the research farm of the Faculty of Agriculture, University of Ruhuna. They were washed with running tap water, rinsed three times in distilled water and oven dried at 50°C for three days. Plant residues were then grounded and passed through a 1-mm sieve and kept in glass sealed containers until analysis and/or incubation was performed. Organic C content of the leaves was determined using wet digestion procedures (Nelson and Sommers, 1982) and Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982) was used in determining the total N content (Table II).

Table II: Carbon and nitrogen content the leaves

Species	C (%)	N (%)
Sesbania grandiflora	40.62	4.93
Caliandra calothyrsus	42.57	3.85
Gliricidia maculata	39.44	4.48

Homogeneously mixed air dried 100 g of soil samples (both saline and non-saline) were placed in cleaned glass bottles. The soils in bottles were watered to adjust the moisture content to 50 % of the field capacity (dry basis) and kept in dark for two weeks prior to addition of plant residues. The moisture content of the soils was monitored daily in order to make sure the sufficient moisture in the bottles. After two-week pre-incubation period, the glass bottles were opened and 235 mg of leaf material were mixed separately with the soil. The application rate was 5 tons per hectare, on the assumption that top 15 cm of an area of 1ha contains 2.13 $X10^9$ kg soil (soil bulk density 1.42 g/cm^3). Soil samples without being amended by plant residue were used as control. The treated soil samples along with the controls were

incubated in the dark at room temperature (25 ± 1°C). Constant moisture content of the soil was maintained throughout the incubation period.

Carbon mineralization

Soil samples were placed in gas-tight glass containers along with a vial containing 10 ml of 1 M NaOH to trap CO_2 and a vial of water to maintain humidity. Soil was incubated at room temperature (25 °C) in the dark and NaOH traps were replaced at 2, 5, 7, 14, 21, 28, 35, 42, 49, 56 and 70 days after the treatment. Unreacted alkali in the NaOH traps was titrated with 0.5 M HCl to determine CO_2 -C released from the soil (Alef, 1995).

Nitrogen mineralization

Nitrogen mineralization was determined in terms of inorganic N (NH_4^+-N and NO_3^--N) concentration of soil extracted at 2, 5, 7, 14, 21, 28, 35, 42, 49, 56 and 70 days after incubation. Samples containing 10 g soil were extracted using 30 ml of 2 M KCl and used to determine NH_4^+-N and NO_3^--N respectively according to Berthelot reaction (Searle, 1984) and sodium salicylate yellow color method (Bremner and Mulvaney, 1982).

Statistical analysis

Data generated were subjected to analysis of variance (ANOVA) for a Completely Randomized Design (CRD) with four replicates using SAS software (SAS Institute, 1988). Least significant difference at $P \leq 0.05$ was used to separate the means.

Results and Discussion

Changes in evolved CO_2-C content from the saline (*EC* = 18.2 dS/m) and non-saline (*EC* = 0.97 dS/m) soils during 10-week period of incubation are depicted in Figure 1. Three residue types amended to the soil resulted in different rates of CO_2 evolution. Under non-saline condition, the highest CO_2-C content was observed in the soil amended with *Caliandra* (1551 mg/kg soil) residues followed by *Sesbania* (1161 mg/kg soil) and *Gliricidia* (1042 mg/kg soil) residues. The C mineralization from saline soil was significantly ($P \leq 0.05$) lesser than that of non-saline soil in all the treatments

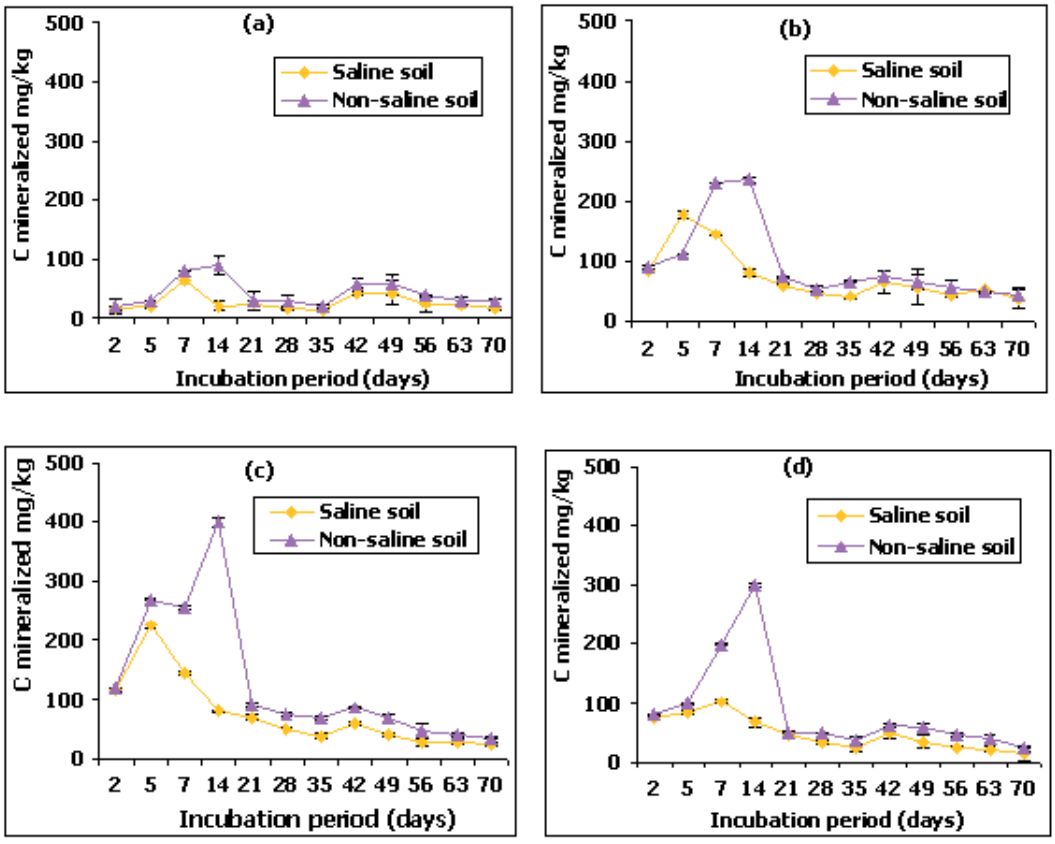

Fig. 1: Carbon mineralization of non-saline and saline soil amended with different plant residues. (a), (b), (c) and (d) respectively represent the control (without plant residues), *Sesbania, Caliandra* and *Gliricidia* amended soils. Values are the means (n = 4) ± standard deviation

irrespectively the residue type. Under saline condition, the evolved CO_2-C content ranged from 313 mg/kg (control) to 905 mg/kg (*Caliandra* residue-amended soil). The greater amounts of CO_2 produced in *Caliandra* residue treated soils can be attributed to the higher biodegradability of *Caliandra* leaves induced by higher C content compared to the other residues. This suggests that the readily decomposable fractions of organic C in *Caliandra* leaves are greater than those in *Sesbania* and *Gliricidia* leaves. The soil salinity caused to reduce the rates of CO_2 evolution by 71.38, 28.57 and 81.51 % respectively in *Caliandra*, *Sesbania* and *Gliricidia* residue amended soils which is in agreement with Pathak and Rao (1998) who also reported a reduction of C mineralization in *Sesbania cannabina* treated saline soil. The reduction may be due to the addition of organic material which, in the short term, could provide additional substrates for the microbial population, resulting high osmotic and pH stress on the microorganisms as reported by Pathak and Rao (1998). The increasing salinity is also likely to be an osmotic stress retarding the activity of the microbial community (Galinski, 1995; Oren, 1999). Osmoregulation becomes a problem and the hypertonic environment tends to dehydrate the microorganisms. Specific ion toxicities (such as Na^+ and Cl^-) may also tend to inhibit microbial growth in saline soils (Zahran, 1997) resulting poor C mineralization. The ameliorative influence of *Sesbania cannabina* residues on CO_2 evolution, microbial biomass, dehydrogenase and urease activities of salt-affected soils also has been reported by Rao and Pathak (1996).

In contrast, the cumulative CO_2-C content of the control was about 33, 44 and 49 % lower than that of *Caliandra, Sesbania* and *Gliricidia* residue amended soils under non-saline condition. The comparative reductions under saline condition were 34, 35 and 54 % respectively for *Caliandra, Sesbania* and *Gliricidia* treated soils. Results further revealed that except *Caliandra* and *Sesbania* treated saline soils, the cumulative CO_2-C content of all the other treatments were significantly ($P \leq 0.05$) different (Figure. 2).

Results revealed that the N mineralization of the soil was a function of the quality of plant residue amended to the soil.

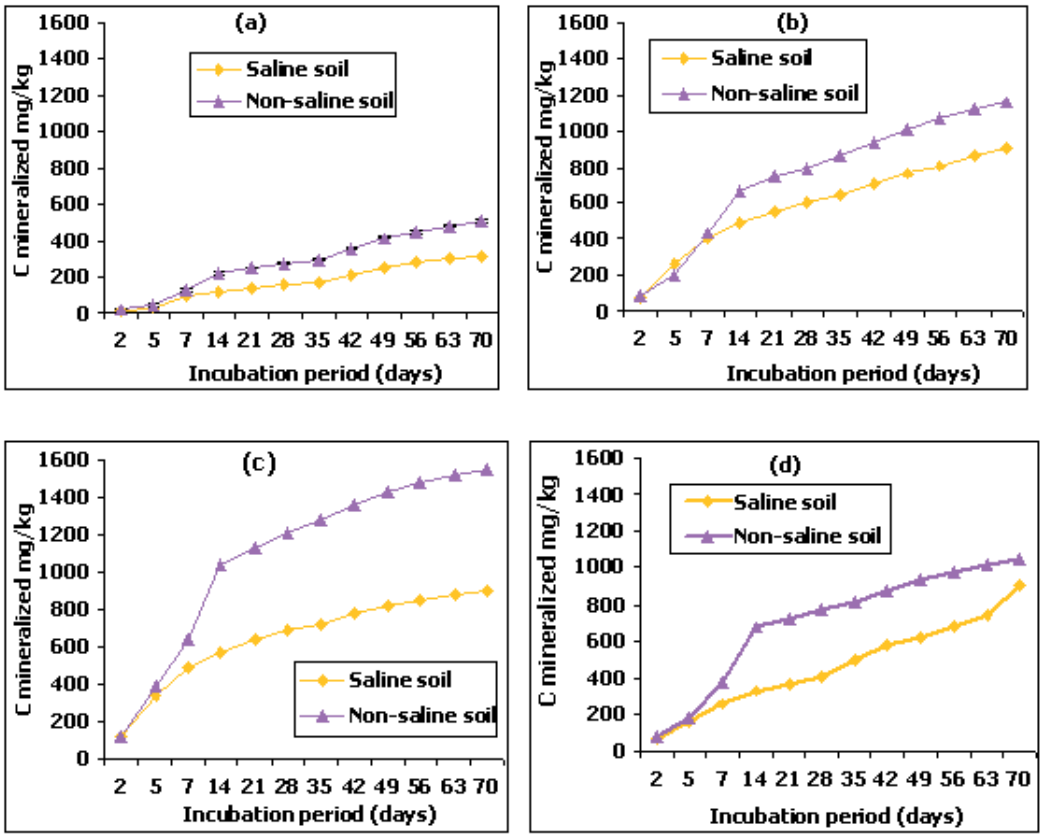

Fig. 2: Cumulative C mineralization of the non-saline and saline soil amended with different plant residues. (a), (b), (c) and (d) respectively represent the control (without plant residues), *Sesbania, Caliandra* and *Gliricidia* amended soils. Values are the means (n = 4) ± standard deviation

As shown in Figure 3, no significant ($P \leq 0.05$) differences were found among three different residue types. However, released NH_4^+-N content from saline soil was found to be significantly ($P \leq 0.05$) lower than that of in non-saline soils throughout the incubation period. Results further revealed that three plant residues applied to the soil resulted in different rates of NH_4^+-N evolution irrespectively the type of soil. Despite the slow NH_4^+-N released during the first week of incubation, a progressive increased in NH_4^+-N content of all the treatments was observed as incubation proceeded. The NH_4^+-N content released during the period between 28 DAI to 35 DAI was higher than the rest of the incubation period for all plant residue amended non-saline soils. However the control reached to the peak NH_4^+-N content at 21 DAI and 5 DAI for non saline and saline soils respectively. After 35 days, a decreasing trend of available NH_4^+-N in the non-saline soil was observed in all the treatments. Though comparatively lower available NH_4^+-N content was observed in plant residue amended saline soils, no distinguish fluctuation was observed throughout the incubation period.

A progressive increased in NO_3^--N contents in both soils for all the treatments including control were found throughout the incubation period as shown in Figure 4. However, irrespectively the treatments, NO_3^--N content of non-saline soil was found to be higher than that of saline soil. *Sesbania* has released higher NO_3^--N contents at every stage of the incubation compared to control and other plant residues. This may be attributed to high quality nitrogen constituents and low protein binding material of *Sesbania* leaves as pointed out by Robertson and Morgan (1995) who discussed the importance of quality of carbon and nitrogen source in the

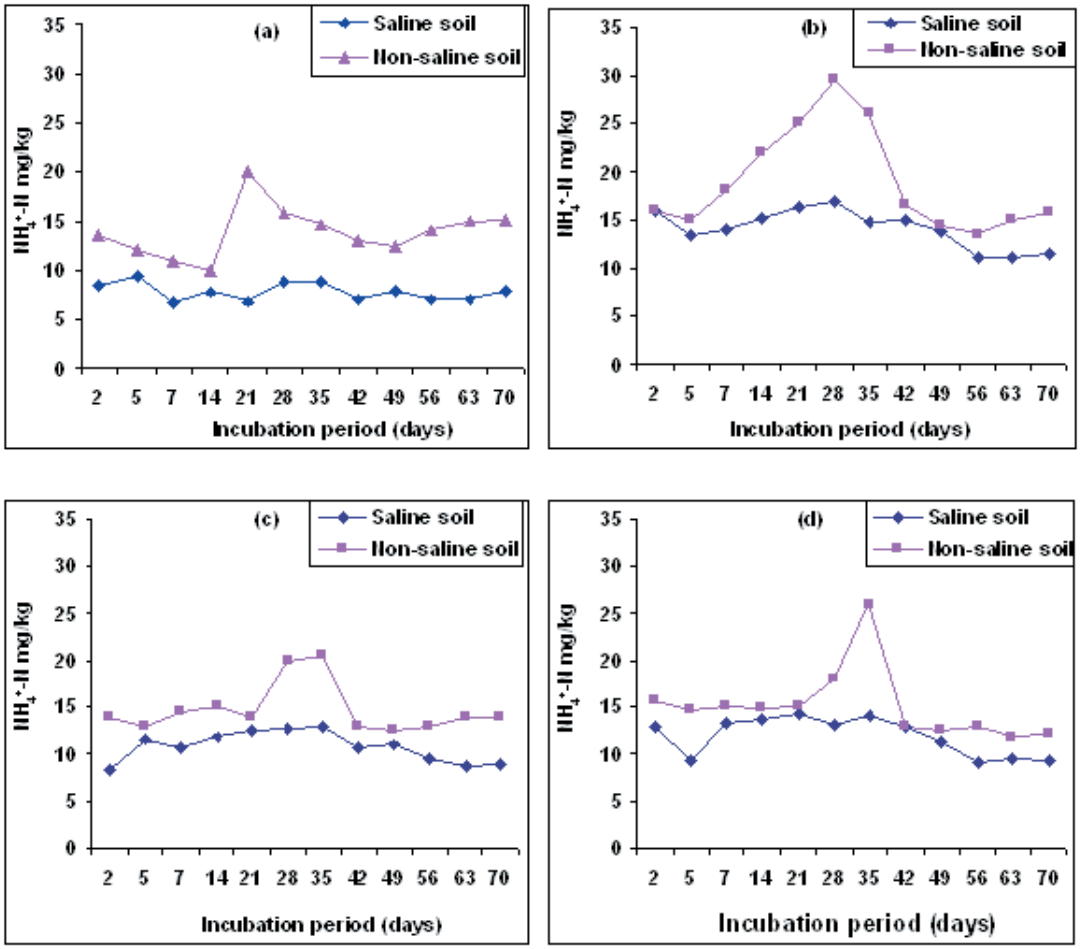

Fig. 3: Release of NH_4^+-N from saline and non-saline soils amended with different plant residues. (a), (b), (c) and (d) represent control (without plant residues), *Sesbania, Caliandra* and *Gliricidia* leaves, respectively. Values are the means (n = 4) ± standard deviation

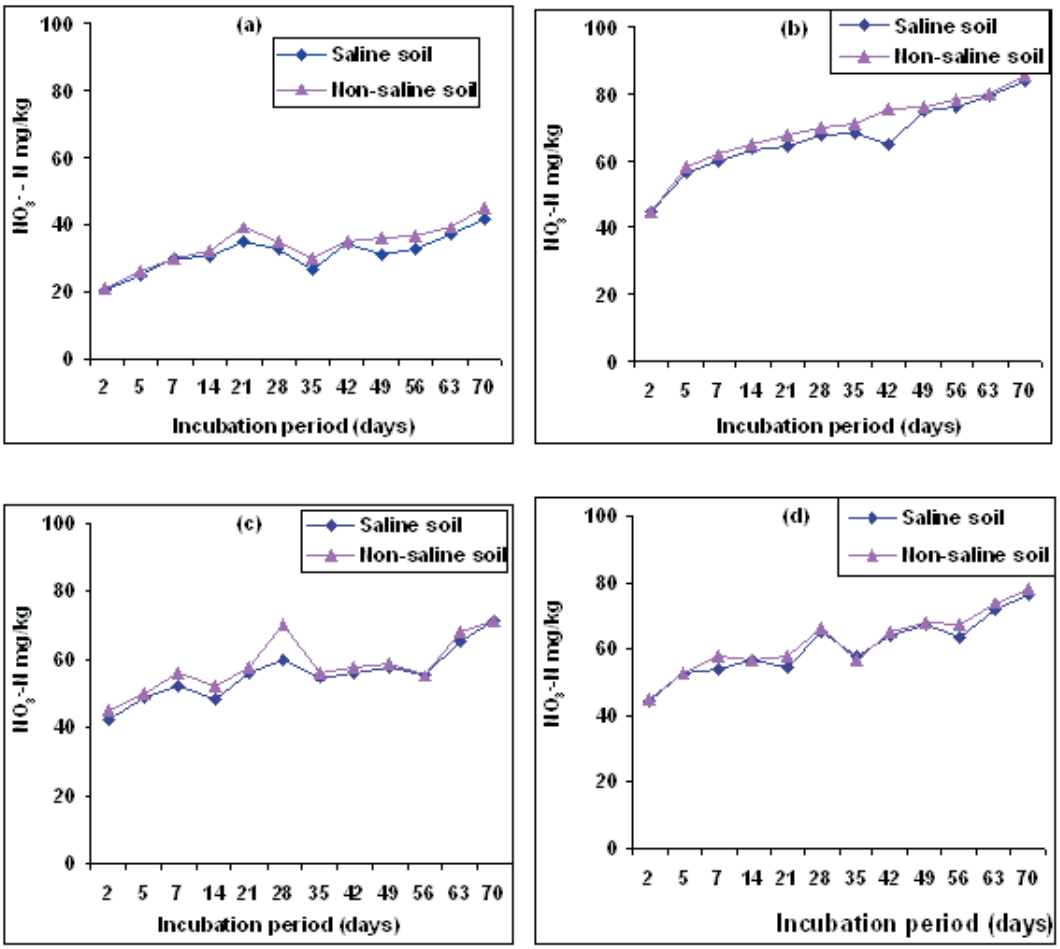

Fig. 4: Release of NH_3^--N from saline and non-saline soils amended with different plant residues. (a), (b), (c) and (d) represent control (without plant residues), *Sesbania, Caliandra* and *Gliricidia* leaves, respectively. Values are the means (n = 4) ± standard deviation

decomposing process. However, according to Nourbakhsh and Dick (2005), the influence of the C/N and lignin/N ratios of the plant residues on the rate of N mineralization is not significant, but the net N mineralization potential is heavily depended upon the N content of plant residues. The conditions under which the present incubation took place were not favorable either for denitrification or leaching out nitrogen from the soil. Continuous increase in NO_3^--N content throughout the incubation is thus due to the nitrification process. Senanayake, (2004) has also reported similar results in nitrogen mineralization of these species. Similar nitrification pattern of NH_4^+-N to NO_3^--N have also reported by Irshad *et al.*, (2005) for saline soils.

Conclusion

Results could be concluded that the response pattern of C and N mineralization to salinity stress is depending upon the type of plant residue incorporated into the soil. The mineralization pattern was found to be varied with the time also. Studies under field conditions would provide better illustration as to how mineralization takes place in plant residue amended saline and non-saline soils.

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