



A kinetic approach to evaluate salinity effects on carbon mineralization in a plant residue-amended soil*

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Abstract: The interaction of salinity stress and plant residue quality on C mineralization kinetics in soil is not well understood. A laboratory experiment was conducted to study the effects of salinity stress on C mineralization kinetics in a soil amended with alfalfa, wheat and corn residues. A factorial combination of two salinity levels (0.97 and 18.2 dS/m) and four levels of plant residues (control, alfalfa, wheat and corn) with three replications was performed. A first order kinetic model was used to describe the C mineralization and to calculate the potentially mineralizable C. The CO₂-C evolved under non-saline condition, ranged from 814.6 to 4842.4 mg CO₂-C/kg in control and alfalfa residue-amended soils, respectively. Salinization reduced the rates of CO₂ evolution by 18.7%, 6.2% and 5.2% in alfalfa, wheat and corn residue-amended soils, respectively. Potentially mineralizable C (C₀) was reduced significantly in salinized alfalfa residue-treated soils whereas, no significant difference was observed for control treatments as well as wheat and corn residue-treated soils. We concluded that the response pattern of C mineralization to salinity stress depended on the plant residue quality and duration of incubation.

Key words: Salinity stress, Carbon mineralization, First-order kinetics, Plant residues, Residue quality

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INTRODUCTION

Salt-affected soils are an important ecological entity in the landscape of semi-arid and arid regions of the world (Pathak and Rao, 1998). The soils occupy more than 7% of the earth land surface and represent a major limiting factor in crop production (Feng *et al.*, 2002). Soil water potential is a critical factor when microbial activities are of concern. The osmotic component of water potential is related to the concentration of soluble salts present (Harris, 1981). McCormick and Wolf (1980) observed decreased CO₂ evolution, ammonification and nitrification in a sandy soil salinized with NaCl. Carbon dioxide evolution from *Sesbania cannabina* residue-amended soils decreased significantly as salinity increased beyond E_{Ce} (electrical conductivity of the saturation

extract) of 16.0 dS/m (Pathak and Rao, 1998). Dehydrogenase enzyme activity was shown to be severely inhibited by salinity whereas, the hydrolases showed a much lesser degree of inhibition (Frankenberger and Bingham, 1982).

Sustainable management of agricultural ecosystems requires incorporation of plant residue in soil. Plant residue input can influence soil organic matter as a result of their quantity and biodegradability (Dick and Gregorich, 2004). The ameliorative influence of *Sesbania cannabina* residues on CO₂ evolution, microbial biomass, dehydrogenase and urease activities of salt-affected soils has been reported (Rao and Pathak, 1996). Crop residues returned to soil may provide significant input of N and easily available C to the decomposer populations. The incorporation of crop residues therefore, has significant influence on the N turnover in soil (Christensen, 2004). Similarly, phosphorus transformations in soil-plant system are controlled by a combination of biological, chemical

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and physical processes which can be affected by plant residue incorporation (Condon, 2004). The release of inorganic forms of N, P and other organically-bound nutrients in soil is functionally associated with carbon mineralization (Mafongoya *et al.*, 2000) and hence, is affected by the salinity stress that inhibits the mineralization of plant materials in soil.

The importance of soil organic C in maintaining soil functionality and as one of the major C pools interacting with atmospheric CO₂ has been acknowledged (Puget and Drinkwater, 2001). A first-order kinetic model can describe the CO₂ evolution in soils amended with various plant materials (Ajwa and Tatabai, 1994). The effects of biochemical composition of organic amendments on their decomposition kinetics have been addressed (Thuriès *et al.*, 2002).

We could not find information regarding the salinity effects on the kinetics of C mineralization in plant residue-amended soils. Besides, the interaction between salinity effects and plant residue initial quality is still obscure. We hypothesized that the biodegradation of plant residues of dissimilar composition would be differently influenced by salinity. The objective of this study was to investigate the effects of NaCl-derived salinity on the kinetic parameters of C mineralization in a soil amended with alfalfa, corn and wheat residues.

MATERIALS AND METHODS

Soil and plant residue characteristics

The soil sample was collected from 0~15 cm depth, Shervedan Research Station (32°30' N, 51°36' E), Isfahan, Iran. The soil (Typic Haplocambid) was clayey (576 g/kg clay and 59 g/kg sand) with pH 8.1, containing 18.01 and 1.96 g/kg organic C and total N, respectively. The soil was calcareous (394 g/kg calcium carbonate equivalent), non-saline ($E_{Ce}=0.97$ dS/m) and non-sodic (sodium adsorption ratio (SAR)=1.42). The soil sample was passed through a 2-mm sieve and kept at 4 °C before the incubation experiment.

Alfalfa (*Medicago sativa* L.) shoots were sampled before flowering. Corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) shoots were sampled one week prior to harvest. Plant residues were washed with running tap water, rinsed three times with distilled

water, then dried at 65 °C for 24 h, passed through a 1-mm sieve and kept in sealed glass containers until analysis and/or incubation experiments.

Hemicellulose, cellulose and lignin content of the plant materials were measured sequentially in duplicate samples (van Soest *et al.*, 1991). Kjeldahl digestion and distillation were used to analyze the residues for total N (Bremner and Mulvaney, 1982). Organic C was determined using wet digestion procedures (Nelson and Sommers, 1982). The initial compositions of the plant residues are summarized in Table 1.

Table 1 Initial composition of the plant materials

Plant	C:N	C (g/kg)	N (g/kg)	CE (g/kg)	HE (g/kg)	LG (g/kg)
Wheat	22.4	413	18.4	234.4	230.5	08.3
Corn	42.3	440	10.4	256.1	254.0	33.4
Alfalfa	12.7	380	29.8	108.9	69.8	28.1

CE: Cellulose; HE: Hemicellulose; LG: Lignin

Soil salinization

An artificially salinized sub-sample was prepared from non-saline soil. For this purpose, the non-saline soil was treated with NaCl at a rate which produced electrical conductivity of the saturation extract (E_{Ce}) of 18 dS/m. The E_{Ce} of 18 dS/m corresponds to 50% reduction in barley yield (Ayers and Westcut, 1985), simulating a saline condition predominantly existing in salt-affected soils. The weight of salt applied was calculated on an oven-dried basis and mixed thoroughly with the soil sample. The actual E_{Ce} level achieved was 18.2 dS/m.

Incubation experiment

To study the C mineralization kinetics, triplicates of 50 g soil samples (both non-saline and salinized samples) were mixed thoroughly with plant residues at the rate of 10 g residue C/kg soil. Moisture was adjusted at 50% water holding capacity. Control treatments without application of plant residues were also run for both salinity conditions. The soils were kept in sealed glass jars containing alkali solution vial (15 ml 1 mol/L NaOH) to trap CO₂-C respired. The jars were kept at 25 °C. The trapping alkali solution was replaced periodically after 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 15, 18, 21, 29, 37 and 46 d of incubation. The CO₂-C trapped was measured by titrating the aliquot

with 0.25 mol/L HCl following precipitation of carbonates by BaCl₂ solution (Alef, 1995).

A first order kinetics equation was used to calculate the potentially mineralizable C (C_0):

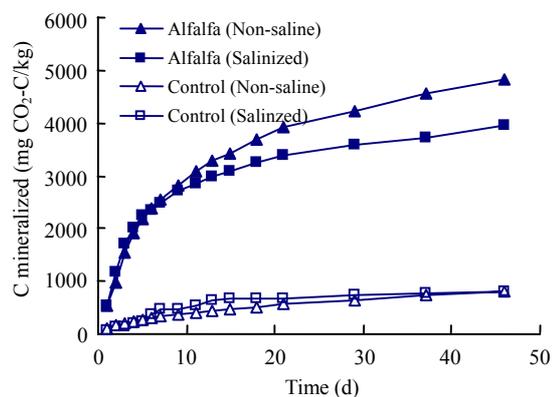
$$C_m = C_0(1 - e^{-kt}),$$

where, C_m is the organic C mineralized at any specific time t , and k is the first order rate constant. SYSTAT (8.1) was used to calculate C_0 and k (Wilkinson, 1988).

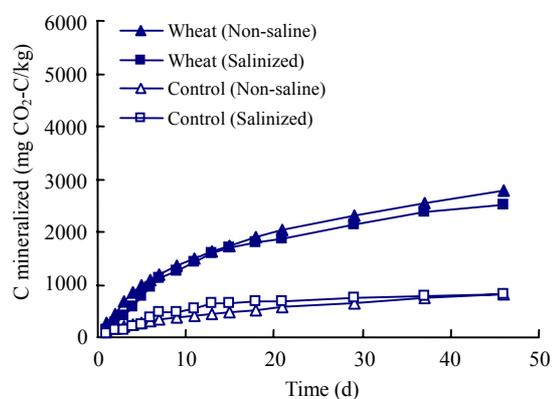
RESULTS AND DISCUSSION

In general, the amount of CO₂-C released from plant residue-treated soils increased at a decreasing rate. This was seen as rapid increase during the initial stages of incubation, followed by a slower, relatively linear release (Fig.1). In this study, the decomposition rate of the native soil organic C in the presence of organic material (priming effect) is assumed to be the same for each type of organic material. The same assumption was made earlier by other researchers (Ajwa and Tabatabai, 1994; Trinsoutrot *et al.*, 2000).

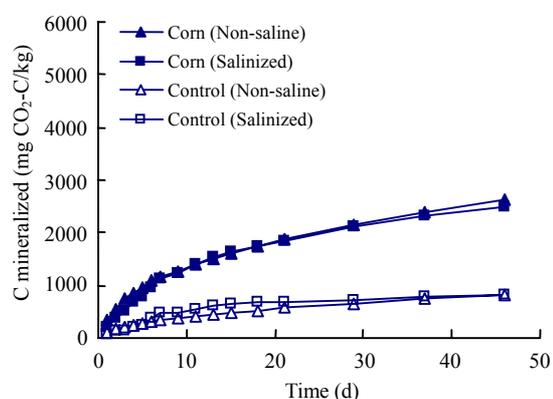
The different initial composition of the three residues applied to the soil resulted in different rates of CO₂ evolution (Table 2). The total amount of CO₂-C released from alfalfa residue treated soils under non-saline condition ($E_{Ce}=0.97$ dS/m) was about 6, 1.9 and 1.4 times that of control, corn residue- and wheat residue-treated soils, respectively (Table 2). Similarly, under salinized condition ($E_{Ce}=18.2$ dS/m), the total amount of CO₂-C released from alfalfa residue treated soils was 4.8, 1.6 and 1.2 times that of control, corn residue- and wheat residue-



(a)



(b)



(c)

Table 2 The cumulative CO₂-C released (C_m) and the percentage of plant C released (C_p) after 46 d of incubation

	Non-saline		Salinized	
	C_m (mg C/kg)	C_p (%)	C_m (mg C/kg)	C_p (%)
Control	814.6 a	—	817.9 a	—
Corn	2620.1 b	18.1 a	2482.8 b	16.7 a
Wheat	3500.0 c	26.9 b	3284.2 c	24.7 b
Alfalfa	4842.4 d	40.3 c	3938.7 d	31.2 c

Different letters in each column indicate significant difference (LSD, $P < 0.05$)

Fig.1 Cumulative amounts of organic C released as CO₂-C from the soil treated with alfalfa residue (a), wheat residue (b), and corn residue (c)

treated soils (Table 2). The greater amounts of CO₂ produced in alfalfa residue-treated soils can be attributed to the higher biodegradability of alfalfa residues induced by higher N content, lower C/N and lignin/N ratios of alfalfa residues (Table 1). In a similar experiment, Nourbakhsh and Dick (2005)

demonstrated that the rate of net N mineralization potential of a calcareous soil treated with a wide range of plant residues heavily depended on the N content of plant residues. The C/N and lignin/N ratios of the plant residues influenced the rate of N mineralization process to a lesser extent.

Expressed as a percentage of organic C in plant residues, the cumulative amounts of C mineralized as CO₂ in 46 d under non-saline condition ranged from 18.1% for corn residue- to 40.3% for alfalfa residue-amended soil. This suggests that the readily decomposable fractions of organic C in alfalfa residues are greater than those in wheat and corn residues. There were considerable differences in chemical composition of the plant residues. Carbon to N ratio varied from 12.7 for alfalfa to 42.3 for corn residues. Since the C contents of the plant materials are not widely ranged, the wide range of the C:N ratios can be attributed to the N concentrations. The N concentration in alfalfa residues was about 3 times that of corn (Table 1). Cellulose and hemicellulose concentrations in the wheat and corn residues were similar, while lignin content in corn residues was about 3.4 times that of wheat. Lignin is known to be a natural recalcitrant and will be subjected to degradation more slowly in soil (Melillo *et al.*, 1982).

The extent of salinity effects on the cumulative CO₂-C emitted and the percentage of plant residue C released as CO₂-C depended on the type of plant residues (Table 2). The non-saline and salinized alfalfa residue-treated soils showed significant differences with respect to the CO₂-C evolved, from day 15 of incubation in alfalfa residue-treated soils. The difference increased as the incubation proceeded (Fig. 1a). Carbon dioxide evolution was not negatively influenced by the NaCl-derived salinity (ECe=18.2 dS/m) in wheat (Fig. 1b) and corn (Fig. 1c) residue-treated soils as well as the control treatment.

The percentage of plant C released in alfalfa residue-amended soils was decreased from 40.3% to 31.2% by salinity whereas, in wheat and corn residue amended soils, very small changes were observed due to salt amendment (Table 2). The results suggest that ECe (18.2 dS/m) can only decrease the decomposition rate of the plant residues containing high amounts of readily decomposable material. Pathak and Rao (1998) reported that ECe 16 (dS/m) decreased the C mineralization rates of *Sesbania cannabina* treated soils.

They suggested that the *Sesbania* residues are readily decomposable, N rich plant material containing 28 g/kg N and with C:N of 15 are commonly used as green manure (Pathak and Rao, 1998). The response pattern of alfalfa residue-amended soil to salinity in the current study is similar to the pattern observed by Pathak and Rao (1998) for *Sesbania cannabina*, however; the response pattern of *Sesbania cannabina* residue-treated soils has not been compared with those of other plant residues to address the interaction of salinity stress and initial quality of the plant residues on the C mineralization. The lack of response in the wheat residue- and corn residue-amended soils to the salinity stress (ECe of 18.2 dS/m) indicated that the decomposition rates of the cereal residues are presumably controlled by their inherently low biodegradability rather than the salinity stress. There are some evidences revealing that low N content of cereal residues is a major limiting factor for their biodegradation in soil (Recous *et al.*, 1995; Trinsoutrot *et al.*, 2000). It can be hypothesized that increasing ECe to levels higher than those examined in the current study may also influence C mineralization of less biodegradable plant residues.

Decomposition kinetics

All results of CO₂-C evolution from plant residue-treated soils conformed well to the exponential model $C_m = C_0(1 - e^{-kt})$ described earlier. The model has been widely used in literature to describe the C (Ajwa and Tabatabai, 1994; Martinez and Tabatabai, 1997) and N mineralization kinetics (El Gharous *et al.*, 1990). The potentially mineralizable C was significantly decreased by salinity stress in alfalfa residue-treated soils (Fig. 2). In contrast, there were no significant differences between non-saline and salinized soil samples either when treated with wheat and corn residues or remained untreated (control treatments). Apparently, ECe as high as 18.2 dS/m can only reduce C mineralization potential in low C/N ratio residue-treated soils in which enough N for decomposer populations can be provided. Carbon mineralization in wheat and corn residue-treated soil seems to be controlled by N shortage rather than salinity stress.

It has been suggested that the product of C₀ and k (kC₀) is more accurate than C₀ (Murwira *et al.*, 1990; Saviozzi *et al.*, 1993). Pascual *et al.* (1998) reported

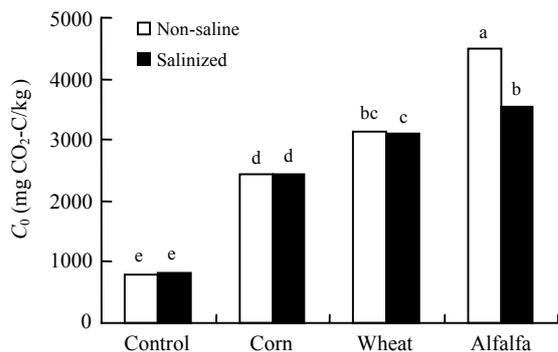


Fig.2 Potentially mineralizable C (C_0) as affected by residue application and salinity
significant difference indicated by different letters, LSD, $P < 0.05$

that the product kC_0 was sensitive to organic waste quality in an arid soil, amended with organic wastes of varying degrees of stability. We observed that kC_0 is significantly decreased by salinity in alfalfa- and wheat-residue treated soils while remaining unaffected in the control and corn residue-treated soils (Fig.3). Heterotrophic soil microorganisms in the control soils are supplied by native soil organic C which is relatively resistant to biodegradation processes. The response pattern of kC_0 in corn-residue treated soils is similar to that of the control soils. Corn residues are shown to be resistant to biodegradation (Recous *et al.*, 1995) and hence, behave similarly as the control treatments. Lastly, this research was done under laboratory conditions where the salinity stress was created by artificial addition of NaCl. Natural sources of salinity may interact differently with plant residue quality when C mineralization is of concern.

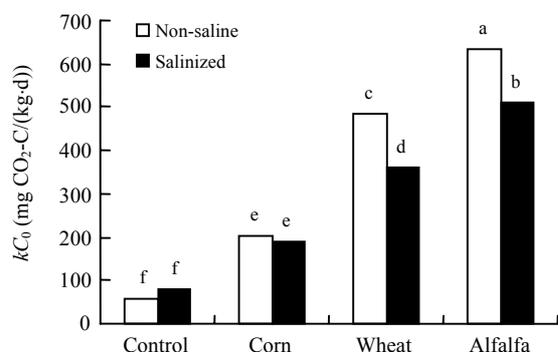


Fig.3 The product of potentially mineralizable C (C_0) and first order rate constant (k) as affected by residue application and salinity
significant difference indicated by different letters, LSD, $P < 0.05$

Overall, we concluded that cumulative CO₂-C released was significantly increased in all residue-treated soils in comparison to the control treatments. Salinity decreased CO₂ emission in treatments received N-rich plant residues, which possess higher amounts of readily biodegradable C. Potentially mineralizable C in salinized soils was influenced differently. The initial chemical composition of the plant residues determined the degree of salinity effects on biodegradation kinetics in residue-applied soils.

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