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Salinity effects on carbon mineralization in soils of varying texture

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ABSTRACT

In salt-affected soils, soil organic carbon (SOC) levels are usually low as a result of poor plant growth; additionally, decomposition of soil organic matter (SOM) may be negatively affected. Soil organic carbon models, such as the Rothamsted Carbon Model (RothC), that are used to estimate carbon dioxide (CO_2) emission and SOC stocks at various spatial scales, do not consider the effect of salinity on CO_2 emissions and may therefore over-estimate CO_2 release from saline soils. Two laboratory incubation experiments were conducted to assess the effect of soil texture on the response of CO_2 release to salinity, and to calculate a rate modifier for salinity to be introduced into the RothC model. The soils used were a sandy loam (18.7% clay) and a sandy clay loam (22.5% clay) in one experiment and a loamy sand (6.3% clay) and a clay (42% clay) in another experiment. The water content was adjusted to 75%, 55%, 50% and 45% water holding capacity (WHC) for the loamy sand, sandy loam, sandy clay loam and the clay, respectively to ensure optimal soil moisture for decomposition. Sodium chloride (NaCl) was used to develop a range of salinities: electrical conductivity of the 1:5 soil: water extract ($EC_{1:5}$) 1, 2, 3, 4 and 5 dS m^{-1}. The soils were amended with 2% (w/w) wheat residues and CO_2 emission was measured over 4 months. Carbon dioxide release was also measured from five salt-affected soils from the field for model evaluation. In all soils, cumulative CO_2–C g^{-1} soil significantly decreased with increasing $EC_{1:5}$ developed by addition of NaCl, but the relative decrease differed among the soils. In the salt-amended soils, the reduction in normalised cumulative respiration (in percentage for the control) at $EC_{1:5} > 1.0$ dS m^{-1} was most pronounced in the loamy sand. This is due to the differential water content of the soils, at the same $EC_{1:5}$; the salt concentration in the soil solution is higher in the coarser textured soils than in fine textured soils because in the former soils, the water content for optimal decomposition is lower. When salinity was expressed as osmotic potential, the decrease in normalised cumulative respiration with increasing salinity was less than with $EC_{1:5}$. The osmotic potential of the soil solution is a more appropriate parameter for estimating the salinity effect on microbial activity than the electrical conductivity (EC) because osmotic potential, unlike EC, takes account into salt concentration in the soil solution as a function of the water content. The decrease in particulate organic carbon (POC) was smaller in soils with low osmotic potential whereas total organic carbon, humus-C and charcoal-C did not change over time, and were not significantly affected by salinity. The modelling of cumulative respiration data using a two compartment model showed that the decomposition of labile carbon (C) pool is more sensitive to salinity than that of the slow C pool. The evaluation of RothC, modified to include the decomposition rate modifier for salinity developed from the salt-amended soils, against saline soils from the field, suggested that salinity had a greater effect on cumulative respiration in the salt-amended soils. The results of this study show (i) salinity needs to be taken into account when modelling CO_2 release and SOC turnover in salt-affected soils, and (ii) a decomposition rate modifier developed from salt-amended soils may overestimate the effect of salinity on CO_2 release.

1. Introduction

Given future climate change projections, it is increasingly important to understand the possible implications of these changes on soils (Smith et al., 2005). Today, salt-affected soils cover large

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areas in countries with dry climates, such as Australia where more than 33% of the total area is affected by salt (NLWRA, 2001), with this area projected to increase further in the future. Salt-affected soils can be classified into saline, sodic and saline-sodic soils (US Salinity Laboratory Staff, 1954). Saline soils have a high concentration of soluble salts and an electrical conductivity of saturation extract (EC_e) greater than 4 dS m^{-1}. Sodic soils typically have a high pH (>8.5) and high (>15) exchangeable sodium percentage (ESP). Saline-sodic soils have an EC_e greater than 4 dS m^{-1} and ESP greater than 15 but their pH is less than 8.5. Electrical conductivity (EC) is usually measured in a saturated paste (EC_e) or at a certain soil: water ratio (e.g. $EC_{1:5}$, $EC_{1:2}$, $EC_{1:1}$). However, the actual salt concentration in the soil solution which is expressed as the osmotic potential, depends on the water content of the soil. At a given salt content of the soil, the osmotic potential of the soil decreases with decreasing water content due to increased concentration of salts in the solution. Therefore, the osmotic potential of soil solution may be a more appropriate parameter for assessing the effect of salt on plant growth than EC (Ben-Gal et al., 2009). This may be particularly important when comparing the effect of salinity in soils of different texture. The water retention capacity of a finer-textured soil is greater than a coarse-textured soil, therefore at a given $EC_{1:5}$ and matric potential, the osmotic potential of the soil solution is lower in the coarse-textured soil. Thus, the higher the clay content, the higher the EC at which crop growth is negatively affected (Sumner et al., 1998).

The accumulation of salts in the root zone has an adverse effect on plant growth by decreasing the availability of water to the plant and affecting the metabolism due to specific ion toxicity and ion imbalances (Sumner et al., 1998). For example, 50% yield reduction occurs at an EC_e of 18 dS m^{-1} for barley, 17 dS m^{-1} for cotton, 7 dS m^{-1} for rice and 13 dS m^{-1} for wheat (Maas and Grattan, 1999). Thus, carbon (C) inputs into salt-affected soils are lower than in non-salt-affected soils.

Soil organic carbon content is a function of C input and C turnover. Turnover of soil organic carbon (SOC) is mediated by soil organisms, mainly microorganisms such as bacteria and fungi. Microorganisms in saline soils are stressed by the low osmotic potential outside of the cells, which causes cells to lose water. Salinity-resistant microorganisms, which can be found in Archaea, Bacteria and Eucarya, can rapidly accumulate salts or organic osmolytes to adjust their intracellular osmotic potential (Oren, 1999). Salt resistance mechanisms are energy demanding and may therefore affect the efficiency of C utilization by microorganisms. The effect of salinity on CO_2 emissions, as a measure of microbial activity, has been studied in incubation experiments by several authors (e.g. Laura, 1974; Pathak and Rao, 1998; Rietz and Haynes, 2003; Tripathi et al., 2007; Yuan et al., 2007). Some studies have shown decreased CO_2 emission (Laura, 1974; Pathak and Rao, 1998; Setia et al., 2010) with increasing salinity due to the decreasing osmotic potential, whereas Wong et al. (2009) showed increased rates of soil organic matter (SOM) decomposition with increasing salinity. Wong et al. (2009) explained this contrasting effect by the increased ionic strength of the solution, which causes release of SOC sorbed onto aggregates. Despite the strong effect of soil texture/water content on salt concentration in the soil solution, there are few systematic studies comparing the effect of salinity on SOC mineralization in soils of different texture (Chowdhury et al., 2011).

Baldock and Skjemstad (1999) divided non-living SOM into four pools: dissolved organic carbon (DOC), particulate organic matter (POM), humus and charcoal. Particulate organic matter consists mainly of macro organic matter >53 μm with a recognisable structure and is important for nutrient release. Humus, which is amorphous and often represents the greatest SOM pool, plays an important role in soil structure and cation exchange. Australian soils often contain high amounts of inert organic matter in the form of charcoal (Baldock and Skjemstad, 1999). Through binding to soil particles, soil organic matter content improves soil structural stability. On the other hand, turnover of SOM provides nutrients such as N and P for plant growth.

Soil carbon models are powerful tools that can be used to predict the effect of soil factors, environmental conditions and land use change on SOC dynamics (Smith et al., 1997). These models describe C flows between different SOC pools. Among published models of SOC dynamics, RothC (Jenkinson et al., 1987; Coleman and Jenkinson, 1996) is used worldwide and has been successfully validated for many non-saline soils (Smith et al., 1997; Coleman et al., 1997). However, RothC does not consider the effect of salinity on CO_2 release, an omission that we hypothesize may lead to inaccurate estimation of CO_2 emissions at point, regional and global scales.

In this study, different EC levels were imposed in four soils of different texture to address the following aims (i) determine the effect of salinity and texture on CO_2 emission and SOC dynamics (ii) evaluate the suitability of EC and osmotic potential as measures of salt stress on organic matter (OM) decomposition (iii) based on these results, develop a decomposition rate modifier to be included into RothC and (iv) compare CO_2–C emission simulated with RothC, modified after including the salt rate modifier, with CO_2–C release of saline soils collected from the field, to determine whether the salt rate-modifier derived from salt amended soils is suitable for simulating the CO_2–C release from saline soils in the field.

2. Materials and methods

2.1. Soils

The study to determine the effect of texture on C mineralization in salt amended soils included two experiments with non-saline and saline soils ($EC_{1:5} < 1.0$ dS m^{-1}) from South Australia. Each experiment was set up as a completely randomised design with three replicates. All soils were collected from the 0–0.30 m layer. One experiment was conducted with a sandy clay loam from Monarto (35° 05′ S and 139° 06′ E), South Australia and a sandy loam collected from Kadina (33° 52′ S and 143° 38′ E), South Australia, and another with loamy sand from Monarto and a clay from Kadina (Table 1). Five additional saline soils were collected from Kadina for model evaluation (see below). The soils were passed through a 2 mm sieve and stored air-dry.

2.2. Soil characterization

The electrical conductivity of soil was measured in a 1:5 soil: water suspension after 1 h of end-over-end shaking at 25 °C. $EC_{1:5}$ was converted to EC_e using the equation proposed by Shaw et al.

Table 1
Physical and chemical properties of experimental soils.

Soil property	Unit	Loamy sand	Sandy loam	Sandy clay loam	Clay
Electrical conductivity	dS m^{-1}	0.08	0.49	0.87	0.32
Sand	%	82.5	69.4	51.3	32.0
Silt	%	11.2	11.9	26.2	26.0
Clay	%	6.3	18.7	22.5	42.0
Bulk density	Mg m^{-3}	1.66	1.47	1.41	1.28
Total organic carbon	%	1.18	3.99	2.93	1.53
Charcoal-C	%	0.0001	0.05	0.08	0.32
Particulate organic carbon	%	0.46	0.45	2.34	0.25
Humus-C	%	0.73	3.49	0.51	0.96

Note: Electrical conductivity was measured in 1:5 soil: water ratio.