CARBON DYNAMICS IN SALT-AFFECTED SOILS

Vanessa N.L. Wong[1,2], Richard S.B. Greene[1], Brian W. Murphy[3], Ram Dalal[4] & Surender Mann[5]

[1]CRC LEME, School of Resources Environment and Society, Australian National University, ACT, 0200
[2]CRC for Greenhouse Accounting, Research School of Biological Sciences, ANU, ACT, 0200
[3]NSW Department of Planning, Infrastructure and Natural Resources
[4]Queensland Department of Natural Resources and Mines
[5]WA Department of Industry and Resources

INTRODUCTION

Saline and sodic soils, termed collectively as salt-affected soils, affect a large area of Australia, with the area affected predicted to increase in the future. While extensive research has been undertaken in the past on the effects of salinity and sodicity on physical and chemical properties of soils, particularly in regards to soil structure and vegetation health, the effects on carbon (C) dynamics with respect to emissions, or losses from soils, is not as well documented. This is particularly pertinent, given the large area affected by salinity and sodicity, usually coincident with agricultural areas, where C stocks are likely to be directly related to decreased plant inputs due to low biomass production and hence, low soil organic matter accumulation. Therefore, two key issues need to be addressed in regards to C dynamics in salt affected areas, firstly, losses of C associated with increasing salinity, especially secondary salinisation on the tablelands and slopes, and secondly, the effect of soil sodicity and increasing sodicity on soil C dynamics.

The issue of salinity has received much attention in recent years as a result of anthropologically-related changes in landscape hydrology and subsequent redistribution of salts. These activities are largely related to the widespread removal of deep-rooted perennial native vegetation and its replacement with shallow-rooted annual crops and pastures, altering the hydrologic balance in the landscape (Bradd *et al.* 1997). A soil is considered saline where the electrical conductivity of a saturated paste extract (EC_e) exceeds 4 dSm^{-1} (Northcote & Skene 1972). At this EC_e, the composition and concentration of salts in the soil solution adversely impacts on plant growth by limiting the absorption of water (through osmotic effects) and through specific ion effects, which can induce ion toxicities (Keren 2000).

Sodic soils are those soils with high levels of exchangeable sodium (Na) on the clay surface. Soil sodicity is expressed in terms of the Exchangeable Sodium Percentage (ESP), which describes the amount of exchangeable Na in relation to the cation exchange capacity of the soil, or the Sodium Adsorption Ratio (SAR) of the soil solution, which describes the ratio of soluble Na^+ to the amount of calcium (Ca^{2+}) and magnesium (Mg^{2+}) according to Equation 1:

$$SAR = [Na]/(0.5[Ca + Mg])^{0.5} \quad \text{(Equation 1)}$$

where Na^+, Ca^{2+} and Mg^{2+} are expressed in $meqL^{-1}$. A sodic soil can be described as saline or non-saline and is considered sodic when the ESP exceeds 6 % in Australia (Northcote & Skene 1972). Non-saline sodic soils can evolve from a saline soil dominated by Na salts when soluble salts are removed from the profile as a result of leaching, or where a fluctuating water table exists with high levels of Na in water. Common problems associated with sodicity include decreased soil aggregate stability as a result of slaking of aggregates, and increased swelling and dispersion. Therefore, soil surfaces swell upon wetting with solutions of low electrolyte content, such as rainfall or many irrigation waters, and form a massive structure which seals and results in a hardsetting soil on drying, with decreased water infiltration and permeability (Oster & Jayawardane 1998).

The rate of C accumulation or loss is dependent on the balance between the amount of C input and C loss. Carbon input is dependent on plant inputs and biomass accumulation, as Soil Organic Carbon (SOC) levels are dominated by deposition from litterfall and roots. Carbon inputs in salt-affected soils are likely to decrease as vegetation health declines due to the direct effects of toxic ions and changes in osmotic potential, and indirect effects in the form of declining soil structure. Where soils are both saline and sodic, plant growth is severely restricted due to constraints in both water and nutrient uptake (Naidu & Rengasamy 1993). Furthermore, as sodicity increases, C losses can be accelerated. The SOC already present in the soil can be lost as sodicity has the potential to mobilise Soil Organic Matter (SOM) as colloidal organic matter or clay-organic complexes (Churchman *et al.* 1993), while Na-organic linkages are highly soluble and mobile, and easily lost by leaching (Naidu & Rengasamy 1993) and runoff.

Increasing the level of SOM, and thus, SOC has been linked to improved soil structure and aggregation (e.g., (Oades 1988, Tisdell & Oades 1982). While SOC displays a continuum of turnover times and levels of decomposition, it is frequently partitioned into a number of discrete pools for analysis, namely an active or labile pool, a slow pool and a passive or recalcitrant pool. The labile pool exhibits a turnover time in the order of weeks and, due to its faster turnover time, can act as an early indicator of soil C dynamics under disturbance. The Soil Microbial Biomass (SMB) is a critical component of the total SOC, even though it usually consists of only 1-5 % (Sparling 1992) and is frequently partitioned into the labile C pool. The SMB thus controls turnover rates of SOC and the mineralisation of organic matter (Killham 1994), which can be determined from soil respiration rates.

Amelioration of sodic soils usually involves the addition Ca ions in the form of gypsum ($CaSO_4.2H_2O$), lime ($CaCO_3$) or salt ($CaCl_2$). Gypsum is the most commonly used soil ameliorant as it is more soluble than $CaCO_3$ and more cost effective than $CaCl_2$. Gypsum can initiate permeability and maintain soil structure by:

1. Providing a source of divalent Ca^{2+} ions which can replace exchangeable Na^+ ions (Keren 1996) according to equations 2 and 3 (Gupta and Abrol 1990):

$$CaSO_4.2H_2O_{(s)} \rightarrow CaSO_{4(aq)} \quad \text{(Equation 2)}$$

$$CaSO_{4(aq)} + 2NaX \rightarrow \downarrow CaX_2 + Na_2SO_4 \text{ (leachable)} \quad \text{(Equation 3)}$$

where X is a clay particle. This process reduces clay dispersion increases and water infiltration and hydraulic conductivity; and,
2. Increasing the electrolyte concentration to levels that prevent clay dispersion, but not to levels that prevent plant growth.

The aim of this study is to assess how C dynamics are affected by salinity and sodicity, and its subsequent effects after amelioration with gypsum. An investigation was conducted to determine the dynamics of the labile C pool in a saline-sodic soil by examining Soil Microbial Biomass Carbon (SMB-C) and soil respiration rates. The effects on C dynamics following amelioration was also investigated.

MATERIALS AND METHODS

Study Site

SMB-C and soil respiration were analysed over a 12 week period. The soil was collected from a property, "Tarcoola" in Bevendale, approximately 40 km south west of Crookwell (34°30'45" S, 149°05'00" E, 510 m ASL), in the Southern Tablelands region of NSW, with average annual rainfall of 860 mm. Samples and bulk density cores were taken from 0-5, 5-10, 10-20, 20-30, and 30-50 cm depths of a soil profile. The soil type was a Yellow Sodosol (Isbell 1996).

Sample Preparation

Samples were stored at 4°C prior to analysis. Bulk density cores were subsampled for moisture and then oven dried at 105°C for 24 hours. Soils that were used for the measurement of microbial biomass and respiration were initially sieved at their field moisture contents through a 5 mm sieve. Sub-samples were then placed into 9.6 L buckets with holes drilled through the bottoms and covered with filter paper. The "unamended" soils were supersaturated with water and allowed to equilibrate for 72 hours (termed *Bevendale* soils). The "amended" soils (termed *Bevendale+gypsum* soils) were prepared with an application (10 t/ha) of nursery grade gypsum and subjected to the same wetting conditions as for the non-amended soils. The soils were then maintained in a constant temperature environment at 25°C for the duration of the incubation, and analysed for respiration and SMB, as described below. All analyses were undertaken in quadruplicate.

Soil Biological Analysis

Soil respiration was determined according to the method described in Edwards (1982) using soda lime traps. Approximately 100 g of soil was weighed into 150 mL screw top jars without lids and placed into air-tight 1.75 L polycarbonate containers. In addition to the soil, a petrie dish with 25 g of soda lime granules was placed in the polycarbonate container to trap the CO_2 evolved, and approximately 15 mL of water in a small vial to maintain the humidity. The soda lime was oven dried at 105°C for 16 hours prior to placing it in incubation jars. The soil samples were left to incubate, and analysed for CO_2 evolution biweekly for a period of 12 weeks. Following removal from the incubation chambers, the traps were oven dried at 105°C for 24 hours and reweighed. The amount of CO_2 evolved was determined using Equation 4:

CO_2 (g) = [(SL_a-SL_b) – B) * 1.69 (Equation 4)

Where SL_a = weight of soda lime after incubation,
SL_b = weight of soda lime before incubation
B = mean blank soda lime gain

CO_2 evolution was then expressed per gram of soil, according to Equation 5:

mg-CO_2 g^{-1} soil = CO_2 (g) evolved / weight of oven dried soil (Equation 5)

Soil microbial biomass was extracted by the chloroform fumigation procedure described in Vance *et al.* (1987). More specifically, approximately 50 g of soil was weighed into a 100 mL beaker, with samples placed in a dessicator with 25 mL of ethanol-free chloroform, and wet filter paper to maintain the humidity within the chamber. The dessicator was evacuated until the chloroform had boiled for 2 minutes, and was placed in the dark for 24 hours. Concurrently, another portion of approximately 50 g of soil was weighed into a 500 mL shaking bottle and was extracted with 200 mL of 0.3 M K_2SO_4. A portion of the filtered extract (8 mL) was placed into a conical flask with 10 mL of concentrated sulfuric acid (H_2SO_4), 5 mL of 85% phosphoric acid (H_2PO_3) and 2 mL of 0.0667 M $K_2Cr_2O_7$. The mixture was heated on a hot plate for approximately 10 minutes and allowed to cool, prior to being titrated against 0.033 M ferrous ammonium sulfate solution with ferroin indicator (1,10-phenanthroline-ferrous sulfate solution). After 24 hours, the beaker with chloroform and filter paper were removed from the dessicator before being repeatedly evacuated to remove the excess chloroform. The fumigated samples were subjected to the same treatment as the unfumigated samples. The extracts were stored for up to two days prior to analysis. The amount of SMB-C present in the samples was determined by the difference between the C in the fumigated samples and the unfumigated samples (E_C), expressed as mg-C/kg oven dry soil using equation 6:

$C = 2.64\ E_C$ (Equation 6)

All measurements were expressed as oven dry weights of soil.

RESULTS AND DISCUSSION

Soil bulk density showed a general increase with depth (Table 1).

Table 1: Soil bulk density with depth.

Depth (cm)	Bulk Density (g cm^{-3})
0-5	1.46
5-10	1.48
10-20	1.56
20-30	1.60
30-50	1.47

As the experiments had been in progress for one week at the time of preparation of this manuscript, the results are only presented for the initial analysis following the equilibration period (week 0). Figure 1 depicts the SMB at a range of depths for the saline-sodic and ameliorated soil. Gypsum was found to increase the SMB compared to the untreated soil from the surface layer to the 10-20 cm layer (week 0; Figure 1).

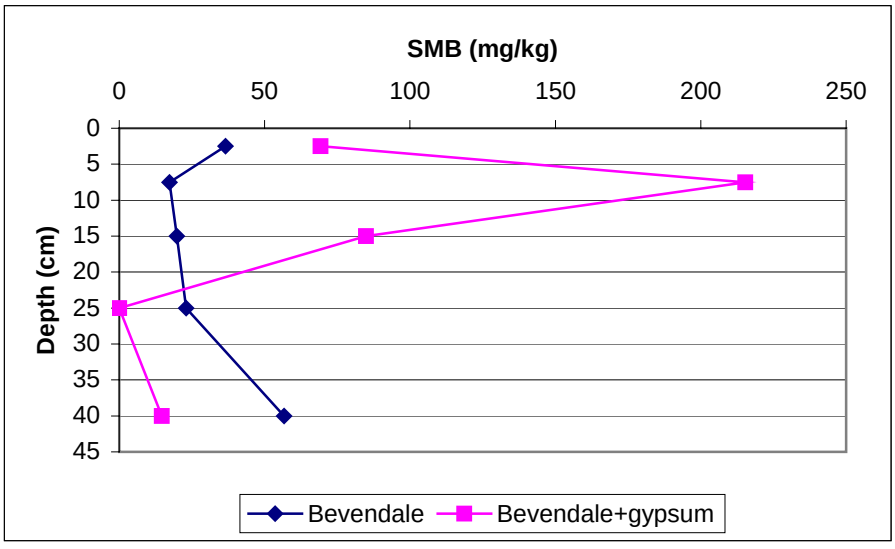

Figure 1: SMB-C with depth at Week 0.

A similar trend was found after Week 1 (data not shown). This pattern is similar to what was found by Carter (1986) in a short term laboratory incubation, who attributed his results to changes in the physicochemical environment caused by the addition of gypsum. The use of gypsum in the amelioration of alkaline saline-sodic soils reduces the soil pH and decreases the SAR by increasing Ca^{2+} ions in the soil solution (Chorom & Rengasamy 1997), which improves soil chemical conditions for the microbial population. Similarly, improvement in soil physical properties can contribute to increased biological activity indirectly by improving soil structure, which allows water and air to pass through pores. Increased biological activity is reflected in increased soil respiration and plant growth (Valzano *et al.* 2001), with this increased activity reflected almost immediately in the SMB in the surface layer.

CONCLUSIONS

At this stage, the soil that has been treated with gypsum has more SMB-C than the untreated soil in the top layers. This could possibly be the result of improvement in soil physical and chemical conditions in the saline-sodic soil.

Analysis of SMB-C and soil respiration will continue to Week 12.

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