THE EFFECTS OF SALINITY AND SODICITY ON SOIL ORGANIC CARBON STOCKS AND FLUXES: AN OVERVIEW

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INTRODUCTION

Soil is the world's largest terrestrial carbon (C) sink, and is estimated to contain approximately 1600 Pg of C to a depth of one metre (Eswaran et al., 1993). The distribution of soil organic C (SOC) largely follows gradients similar to biomass accumulation, increasing with increasing precipitation and decreasing temperature. As a result, SOC levels are a function of inputs, dominated by plant litter contributions and rhizodeposition, and losses such as leaching, erosion and heterotrophic respiration. Therefore, changes in biomass inputs, which affect organic matter accumulation, will most likely also alter these levels in soils. Although the soil microbial biomass (SMB) only comprises 1-5% of soil organic matter (SOM; Sparling, 1992), it can provide an early indicator of SOM dynamics as a whole due to its faster turnover time. Hence, it can be used to determine soil C dynamics under changing environmental conditions (Killham, 1994).

Approximately 932 million ha of land worldwide are degraded due to salinity and sodicity, usually coinciding with land available for agriculture. Of this area, salinity affects 23 % of arable land while saline-sodic soils affect a further 10 % (Szabolcs, 1989). In Australia, approximately 17 million ha of land is affected by salinity, while sodicity affects approximately 340 million ha (Szabolcs, 1989), usually coinciding with agricultural areas. Soils affected by salinity, i.e. those soils high in soluble salts, are characterised by rising watertables and waterlogging of lower lying areas in the landscape. Sodic soils are high in exchangeable sodium, slake and disperse upon wetting. On drying, massive hardsetting structures are formed, which suffer from poor soil-water relations largely related to decreased permeability, infiltration and the formation of surface crusts. In these degraded areas, SOC levels are likely to be affected by declining vegetation health and hence, decreasing biomass inputs and concomitant lower levels of SOM accumulation.

An increase in salinity and sodicity directly impacts upon plant vigour through changes in osmotic potential, ion toxicities and deficiencies. Indirect effects on vegetation can result from altered soil conditions such as increased dispersion and decreased permeability. Moreover, potential SOC losses can be higher from dispersed aggregates due to sodicity and solubilisation of SOM as a result of salinity. Therefore, changes in salinity and sodicity affect soil physical and chemical properties, which subsequently alter nutrient cycles and decomposition processes. The risk of erosion is increased, while soil physical and chemical properties are altered, impacting upon aggregation and nutrient cycling as well as biotic activity. Therefore, there is a clear linkage between land management practices through their effect on salinity and sodicity and their potential to alter soil C stocks and fluxes in the landscape, particularly in regards to land degradation and subsequent rehabilitation efforts (eg. Wong et al., 2005). Despite the large area affected by salinity and sodicity, data on the magnitude and mechanism of changes in soil C stocks in these degraded environments remains sparse. In addition, few studies are available that unambiguously demonstrate the effect of increasing salinity and sodicity on soil C dynamics (eg. Nelson et al., 1997, Nelson et al., 1996, Pankhurst et al., 2001, Sarig et al., 1993).

The overall aim of this project is to determine how soil C stocks and turnover rates are affected by land degradation through increasing salinity and sodicity, and the extent of hysteresis these systems exhibit upon rehabilitation. The project has the following objectives:

- Quantification of the effect of different levels of salinity and/or sodicity on C stocks and fluxes along a salinity and sodicity gradient under controlled conditions in the laboratory,
- Determination of the behaviour of the labile C pool in a saline-sodic soil, and with gypsum amendment over a 12 week period in controlled conditions,
- Determination of how decomposition is affected in saline-sodic soils with and without gypsum amendment following the addition of organic material in controlled conditions, and
- Quantification of soil C stocks in salt-affected scalds using a paired sites approach

EFFECT OF PREPARED SALINE AND SALINE-SODIC SOILS ON THE SOIL MICROBIAL BIOMASS

The effect of increasing salinity and sodicity on C dynamics was determined by subjecting a non-saline non-sodic soil to one of six treatments (Wong et al., 2004). Briefly, a low, mid or high salinity solution (EC 0.5, 10 and 30) combined with a low or high sodicity solution (SAR 1 and 30) in a factorial design was leached through a non-saline non-sodic soil in a controlled environment. Soil respiration and the SMB were measured over a 12-week experimental period. The greatest increases in the SMB occurred in the treatments of high-salinity high-sodicity and high-salinity low-sodicity (Figure 1). Two competing processes occur in saline and sodic soils which affect the SMB and microbial activity; increasing osmotic potential as salt concentration increases, and increasing availability of organic matter through dispersion, dissolution or hydrolysis by salts. Increasing salt concentrations have the potential to increase the amount of dissolved organic C available to the microbial population either by dissolving organic matter, or by converting it either to a more dispersed form (disaggregation) or one that is more easily decomposable and hence, more readily available.

When organic matter is solubilised into colloidal form, the increased availability of substrate can counter some of the environmental stresses on the microbial population (Pathak and Rao, 1998), such as those caused by increased osmotic stress and ion toxicities. The increase in the SMB in this study was attributed to solubilisation of SOM which provided additional substrate for decomposition for the microbial population. Higher salt concentrations increased the microbial population over the 12-week experimental period, in the longer term. However, continued dissolution of organic matter and its mineralisation can lead to increased losses of SOC stocks, particularly in areas where biomass inputs are decreased as a result of degraded environmental conditions brought on by increasing salinity and sodicity.

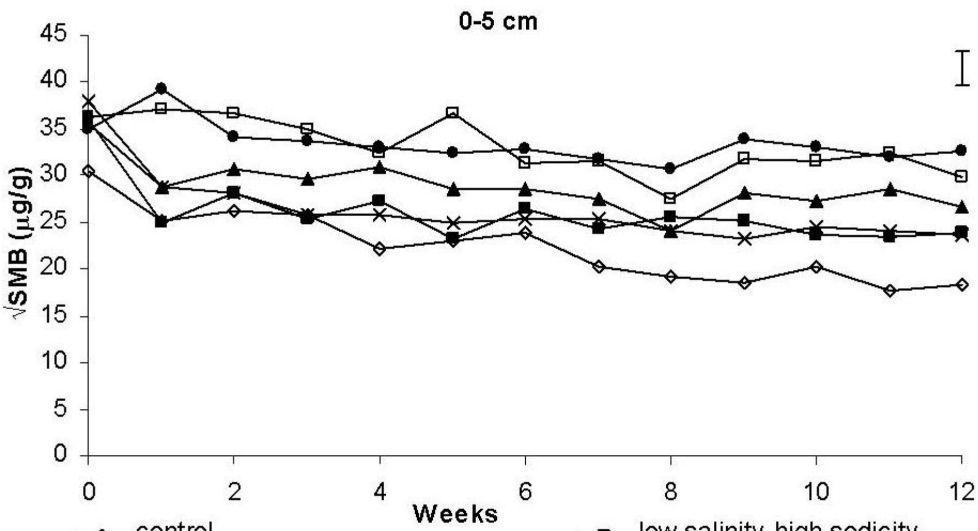

Figure 1. Salinity and sodicity effects on the SMB in the 0-5 cm layer over the 12-week incubation period following an analysis of variance (ANOVA) with GENSTAT 8.0 (Payne, 2005). Vertical bar indicates the least significant difference (LSD). Note that data have been square-root transformed to satisfy assumptions ANOVA.

SOIL MICROBIAL BIOMASS IN SALT-SCALDED PROFILES

Gypsum ($CaSO_4.2H_2O$) is the most commonly applied ameliorant to rehabilitate adverse soil environmental conditions in sodic and saline-sodic soils. Its addition facilitates the replacement of exchangeable Na^+ with Ca^{2+} by balancing the surface charge of the clay, and increasing the electrolyte level of the soil-water which causes compression of the diffuse double layer, thus preventing dispersion (Quirk, 2001).

Wong et al. (2004) simulated saline and sodic effects on the SMB and soil respiration from soil sampled from a non-degraded profile. When soils were sampled from saline-sodic profiles in salt-scalded areas, SMB levels were reported to be very low in the saline-sodic soil compared to the normal non-degraded soil (Figure 2; Wong et al., 2005). Where the saline-sodic soils were treated with gypsum, no change in the SMB was observed. Because the soils were sampled from salt-scalded profiles, low SOC stocks (data not shown) were due to the absence of vegetation, with C inputs likely to be external and related to depositional processes. The low levels of SMB and respiration rates were the result of the low levels of SOC in these highly degraded landscapes. Under such circumstances, any treatment effects were negligible.

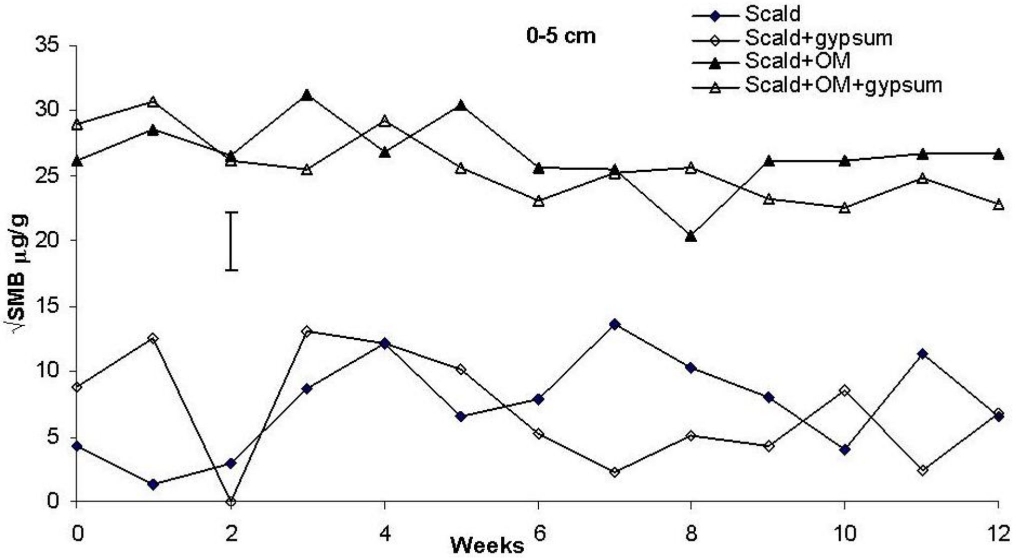

Figure 2. Gypsum and organic material addition effects on the SMB in the 0-5 cm layer of a salt-scalded profile over the 12-week incubation period following ANOVA. Vertical bar indicates the LSD. Note that data have been square-root transformed to satisfy assumptions for ANOVA.

DECOMPOSITION OF ADDED ORGANIC MATERIAL

In contrast, the addition of organic material to salt-scalded soils, resulted in an increase in the SMB to levels greater than those found in the non-saline non-sodic soil (Figure 2; Wong et al., 2005). The addition of gypsum (with organic material) resulted in no additional increases in the SMB. While SMB levels are very low in scalded soils, it is likely that the microbial population present in these soils is a dormant population of salt-tolerant micro-organisms. Where organic material is available as substrate for decomposition, the population multiplies rapidly to decompose the readily available material. Therefore, decomposition processes in these hostile environmental conditions are most likely limited by substrate rather than by the deleterious soil conditions commonly found in salt-scalded areas. Where biomass production is limited by high sodicity and salinity levels, the potential exists for these degraded areas to return to functioning soil ecosystems. Where rehabilitation efforts are successful in re-introducing plant growth into scalded areas, the production of organic material, and therefore SOM, can develop into a self-sustaining process and aid in the restoration of soil ecosystem processes.

SOIL ORGANIC CARBON STOCKS IN SALT-SCALDED SOILS

The level of SOC stocks in salt-scalded, vegetated, and revegetated profiles was determined to establish the amount of SOC lost due to salinisation and sodication, and the increase in SOC following revegetation. Soils were sampled from the property, "Gunyah" in Rugby, approximately 35 km east of Boorowa in the Southern Tablelands region of New South Wales, Comparisons were made between scalded and non-scalded profiles.

The soil profiles were located on a bare scalded patch which had lost its A horizon due to erosion (*Eroded*), a bare scalded patch which had not been eroded (*Scald*), a vegetated patch vegetated with what is assumed to be the original vegetation (*Vegetated*), and an area that had been reclaimed by revegetation (*Pasture*).

The results show up to three times less SOC in salt-scalded profiles compared to vegetated profiles under native pasture. Formerly scalded areas revegetated with introduced pasture displayed SOC levels comparable to those profiles under native pasture to a depth of 30 cm (Figure 3). Vegetation is a major determinant in the relative distribution of SOC as a result of patterns of input (Jobaggy and Jackson, 2000) in particular, the vertical distribution of plant roots (Jinbo et al., 2006). Hence, where little or no vegetation occurs on the surface, as was the case in the *Scald* and *Eroded* profiles, limited C input is occurring, as reflected in the low SOC stocks. The loss of SOC in the *Eroded* profile, particularly in the topsoil, highlights the importance of preserving the upper layers of soil. In addition to the decrease in SOC, losses of topsoil result in a decrease in soil fertility and resilience, and hence, an increase in susceptibility to further erosion. With continued erosion, losses of SOC also increase as SOM is concentrated near the soil surface and is of relatively low density. However, following revegetation with pasture, SOC stocks were increased to a level comparable to that under native vegetation. These results indicate that successful revegetation of scalded areas has the potential to accumulate SOC stocks to levels similar to that found prior to degradation.

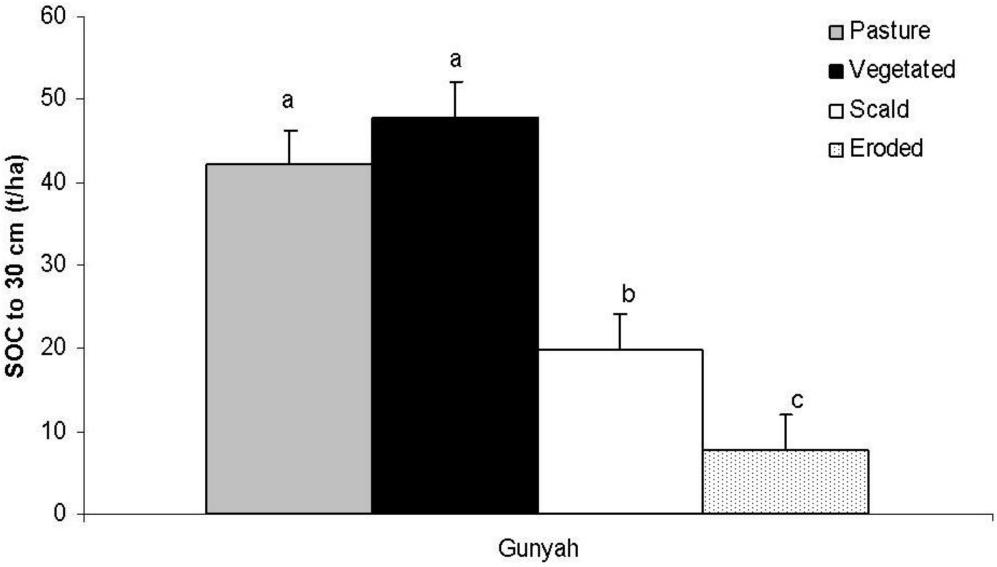

Figure 3. SOC stocks to 30 cm from the revegetated scald profile (Pasture), the vegetated profile (Vegetated), the salt-scalded profile (Scald) and the salt-scalded profile with an eroded A horizon (Eroded) from a property "Gunyah". Vertical bars indicate the LSD following analysis by ANOVA. Different letters above a column indicate a significant difference.

SUMMARY AND CONCLUSIONS

Experimental results from this project indicate that in salt-affected landscapes, initial increases in salinity and sodicity result in a decrease in soil C through a number of mechanisms. With the onset of salinity and sodicity, native SOM is rapidly lost as its solubility, decomposability and accessibility increases. Concurrently, C inputs into the soil are decreased as salinity and sodicity cause plant health to decline as a result of adverse soil physical and chemical conditions. Under these conditions, concentrations of dissolved organic C increase due to increased solubility of SOM, which provides additional substrate which is easily decomposable for the microbial population. Increased solubility of SOM can result in further losses by leaching. Dispersion of aggregates, often with cores containing organic material (Tisdall and Oades, 1982), caused by sodicity, also increases the availability of C, resulting in an increase in its accessibility and degradability for the microbial population. This process also contributes to the rate of SOM loss. Additional SOC is also released from clays with increases in salinity due to exchange processes as cations flood exchange sites.

As salinisation and sodication continues, SOC is continuously lost through the processes described, while inputs are further limited due to declines in vegetation health. At high salinity and sodicity levels, death of vegetation results in bare, scalded patches which are highly susceptible to water and wind erosion, and deflation causing further losses of SOC. The SMB is placed under increasing stress as substrate availability and decomposability decline, while little SOC input occurs due to the absence of vegetation. Vegetation death, which results in scalding of the soil surface will generally precede the decline in SMB, as vegetation is generally less tolerant of saline and sodic conditions compared to the microbial population. Over time, microbial populations can become adapted to a high salt environment (Polonenko et al., 1981, Zahran, 1997) and rapidly multiply when substrate becomes available despite adverse soil conditions, either through direct incorporation of organic material in the rehabilitation process or through increasing vegetation cover.

Due to very low SOC stocks in salt-scalded profiles, successful efforts in revegetating these landscapes will generally result in SOC accumulation. Revegetation with introduced pasture can result in an increase in SOC stocks to levels similar to that found under native pasture. Where salt-affected soils are revegetated, the C sequestration potential in these degraded areas is high, as soil ecosystem function can be restored if organic material is available for decomposition.

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