

# The effects of salinity and sodicity on soil carbon turnover

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## Abstract

Increasing salinity and sodicity affects soil carbon dynamics, with soil carbon levels dependent on a balance between inputs and losses. Since inputs are largely related to biomass production, with soil conditions affecting microbial activity, increasing salinity and sodicity levels can potentially alter carbon (C) stocks and fluxes in the landscape. These processes can lead to a decline in vegetation health and plant biomass production, and a decrease in a soil's productive capacity. Carbon inputs to the soil subsequently decrease due to declining vegetation biomass and increasing erosion. Thus land management practices, particularly in regards to land degradation and its subsequent rehabilitation, have the potential to alter soil carbon stocks and fluxes in the landscape. However, information on the effects of different levels of salinity and sodicity on microbial activity, and carbon fluxes is sparse, especially from Australian saline and sodic landscapes.

The effect of salinity and sodicity on labile carbon was determined by subjecting a non-saline, non-sodic soil to one of six treatments, a low, mid or high salinity treatment with a low or high sodicity treatment in a factorial design within a controlled environment. Soil microbial biomass (SMB) carbon was determined weekly over a 12-week period and soil respiration measured biweekly for the same period. Results for soil microbial biomass show:

- decreasing values for all treatments to week one,
- increasing from week one to week eight, before stabilising.

The greatest increases in SMB occurred in those treatments with the highest salinity and sodicity, largely due to increased substrate availability for the microbial population. Thus, soil C solubilized by high salinity and sodicity levels is likely to be lost from soil not only in microbial respiration but also in runoff and erosion.

## Key Words

Laboratory incubation, soil organic carbon

## Introduction

The soil carbon pool is the world's largest terrestrial store of carbon (Post *et al.* 1982), with changes in land use and land management practices affecting soil carbon stocks and fluxes. The distribution of soil organic carbon (SOC) follows gradients similar to that of biomass accumulation, increasing with increasing precipitation (Post *et al.* 1982) and decreasing temperature (Burke *et al.* 1989). 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, or organic matter accumulation will most likely also alter these levels in soils. The beneficial effects of increasing soil organic matter (SOM) content in agricultural soils, and thus, SOC, are well documented, and largely relate to improved soil structure and aggregation (eg. Oades 1988; Tisdall and Oades 1982). However, little is known about the effects of increasing salinity and sodicity on soil carbon dynamics and microbial activity.

Increasing soil salinity in Australia is a serious land degradation issue, with the area affected by dryland salinity estimated to be approximately 4 million ha in 2000, and is predicted to increase to 20 million ha by 2020 (NLWRA 2001). The main cause of salinity is largely attributed to the broadscale clearing of native deep-rooted perennial vegetation, and its replacement with shallow-rooted annual crops and pastures, altering the hydrologic balance in the landscape. Sodic soils occur both naturally and as a result of anthropogenic activities, occupying approximately 2 million ha in Australia (Rengasamy and Olsson 1991), with sodicity expressed in terms of exchangeable sodium percentage (ESP) or the sodium adsorption ratio (SAR). The deleterious effects of salinity and sodicity on soil physical and chemical

properties are well known, and ultimately cause declines in plant growth. Because SOC is a function of plant inputs and losses, increasing salinity and sodicity will most likely cause declines in biomass accumulation, C fluxes and alter SOC levels.

Carbon fluxes from soil are a result of microbial activity or soil microbial biomass. The soil microbial biomass (SMB) is frequently partitioned into the labile carbon pool due to its faster turnover time compared to soil organic matter as a whole (SOM), and therefore acts as an early indicator of carbon dynamics under disturbance. While the microbial biomass carbon usually only comprises 1-5% of the total soil organic carbon (Sparling 1992) it is the driving force of most terrestrial ecosystems, controlling turnover rates and mineralisation of organic substrates (Killham 1994).

Few studies have examined the effects of salinity and/or sodicity on soil biological processes, often with contradictory results (eg. Chander *et al.* 1994; Laura 1973; Laura 1976; Nelson *et al.* 1996; Rietz and Haynes 2003; Sarig *et al.* 1993). This paper examines the effects of a range of salinity (EC) and sodicity levels (SAR) in soil solution systems on labile carbon by assessing changes in the SMB and respiration rates under controlled temperature and moisture conditions.

## Materials and Methods

### Site Description

The study area was located on a property "Tarcoola" in Bevendale, approximately 40 km south west of Crookwell (34 30' 45" S, 149 05' 00" E, 510 m a.s.l), in the Southern Tablelands region of NSW. Climate data have been taken from Crookwell, the nearest meteorological station, with average annual rainfall of 860 mm. Average maximum temperature for the area is 26.5°C in January with the average minimum temperature of -0.4°C in July. The soil profile used in the study was a yellow Chromosol (Isbell 1996) and was located in an area that had been fenced off from stock dominated by red grass (*Bothriochloa* spp).

### Field Sampling

Samples were taken from 0-5, 5-10, 10-20, 20-30, 30-50 cm depths of a soil profile, transported back to the laboratory in polyethylene bags, and stored at 4°C prior to analysis. Bulk density cores with a diameter of 4.7 cm and height 5.3 cm were also taken from each depth.

### Sample Preparation and Soil Chemical Analyses

Soil properties of the soil profile are listed in Table 1. Bulk density cores were oven dried at 105°C for 24 hours. 1:5 soil:water suspensions were analysed for pH and EC. Soluble cations were analysed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) in the 1:5 soil:water extracts. Exchangeable cations in 1:5 soil:1 M ammonium acetate (CH<sub>3</sub>COONH<sub>4</sub>) extracts were buffered to a pH of 7 and also determined by ICP-AES. Organic carbon was determined by dichromate oxidation and back titration with 0.4 M ferrous sulfate (FeSO<sub>4</sub>.7H<sub>2</sub>O) (Nelson and Sommers 1982). The samples were not pre-treated with acid prior to organic carbon analysis as the soil pH values (pH < 7) indicated that carbonates were not expected to be present (Table 1).

**Table 1. Soil properties of the sampled soil**

Depth (cm)	pH <sub>1:5</sub>	EC <sub>1:5</sub> (dS m <sup>-1</sup> )	SAR	Organic Carbon (%)	Bulk Density (g g <sup>-1</sup> )
0-5	5.91	0.33	0.70	2.51	0.79
5-10	5.94	0.36	1.41	1.19	1.14
10-20	5.88	0.62	1.30	0.72	1.54
20-30	5.80	0.84	1.45	0.40	1.51
30-50	5.93	1.4	1.41	0.34	1.61

### Soil Biological Analyses

Soils that were analysed for microbial biomass and respiration were initially sieved without drying through a 5 mm sieve. Six salt solutions of known EC and SAR values were prepared using a combination of Na<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup> and K<sup>+</sup> ions in the form of chloride salts. The salinities of the solutions were 0.5, 10 and 30 dS m<sup>-1</sup>, and were combined with two SAR values of 1 and 30 in a factorial design, termed low, mid and high salinity and low and high sodicity, respectively. Tap water was used in place of the low salinity-low sodicity solution as a control, giving a total of six solutions used for leaching. More specifically, the following solutions were used:

- Low salinity-low sodicity of EC 0.5 and SAR 1 (control)
- Low salinity-high sodicity of EC 0.5 and SAR 30 (EC0.5SAR30)
- Mid salinity-low sodicity of EC 10 and SAR 1 (EC10SAR1)
- Mid salinity-high sodicity of EC 10 and SAR 30 (EC10SAR30)
- High salinity-low sodicity of EC 30 of SAR 1 (EC30SAR1)
- High salinity-high sodicity of EC 30 and SAR 30 (EC30SAR30)

The soils were treated with the above solutions as follows. Approximately 5 kg of soil was placed into a 9.6 L bucket with holes in the base, with filter paper placed over the holes. The soils were leached once a day for three days, initially with 1 L of solution on the first day, and 0.5 mL solution on the subsequent days before being allowed to drain for 72 hours. The soils were then maintained in a constant temperature environment at 25°C and analysed for respiration and SMB, described below.

### *Soil Respiration*

Soil respiration was determined according to the method described in Edwards (1982). 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 also placed in the polycarbonate container to trap the CO<sub>2</sub> evolved, and approximately 15 mL of water in a small vial to maintain the humidity. The soda lime traps were oven dried at 105°C for 16 hours prior to incubation. 4 mL of water was then added, as the reaction between hydroxide and CO<sub>2</sub> is facilitated by the presence of water. The traps were left to incubate, and were analysed for CO<sub>2</sub> evolution biweekly for a period of 12 weeks. Moisture loss was determined at four weekly intervals gravimetrically, with water added to bring the soils up to their original weight. The traps were oven dried at 105°C for 24 hours after removal from the incubation chambers, and reweighed. The amount of CO<sub>2</sub> evolved was determined using the following equation:

$$\text{CO}_2 \text{ (g)} = [(\text{SL}_a - \text{SL}_b) - B] * 1.69$$

Where SL<sub>a</sub> = weight of soda lime after incubation,  
 SL<sub>b</sub> = weight of soda lime before incubation  
 B = mean blank soda lime gain

CO<sub>2</sub> evolution was then expressed per gram of soil, according to the following equation:  
 mg-CO<sub>2</sub> g<sup>-1</sup> soil = CO<sub>2</sub> (g) evolved / weight of oven dried soil.

### *Soil Microbial Biomass*

Soil microbial biomass was extracted by the chloroform fumigation procedure described in Vance *et al.* (1987). More specifically, two portions of 50 g of soil were weighed into 100 mL beakers, with samples placed in a dessicator together with 25 mL of ethanol free chloroform and wet filter paper to maintain the humidity within the chamber. A liquid nitrogen trap was placed between the dessicator and the pump to trap water and chloroform for disposal. The dessicator was evacuated until the chloroform boiled for 2 minutes prior to being placed in the dark for 24 hours. Concurrently, two portions of 50 g of soil were weighed into 500 mL shaking bottles, extracted with 200 mL of 0.3 M K<sub>2</sub>SO<sub>4</sub> and filtered through Whatmans No. 42 filter paper. Subsequently, 8 mL of the filtered extract was placed into a conical flask with 10mL of concentrated sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), 5 mL of 85% phosphoric acid (H<sub>2</sub>PO<sub>3</sub>) and 2 mL of 0.0667 M K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>. The mixture was heated on a hot plate for approximately 20 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 of chloroform and filter paper was removed from the dessicator before being repeatedly evacuated to remove the excess chloroform. The fumigated samples were subjected to the same treatment as the non fumigated samples. The extracts were stored for no more than three days prior to analysis. The amount of soil microbial biomass carbon present in the samples was determined by the difference between the carbon in the fumigated samples and the unfumigated samples (E<sub>C</sub>) expressed as µg-C/g oven dry soil using the following equation:

$$C = 2.64 E_C$$

All measurements are expressed on oven dry weights of soil.

## Results

### Soil Characterisation

Soil properties were altered after leaching, with the pH, EC and SAR values of the leached soils after the equilibration period of three days shown in Figures 1, 2, and 3 respectively.

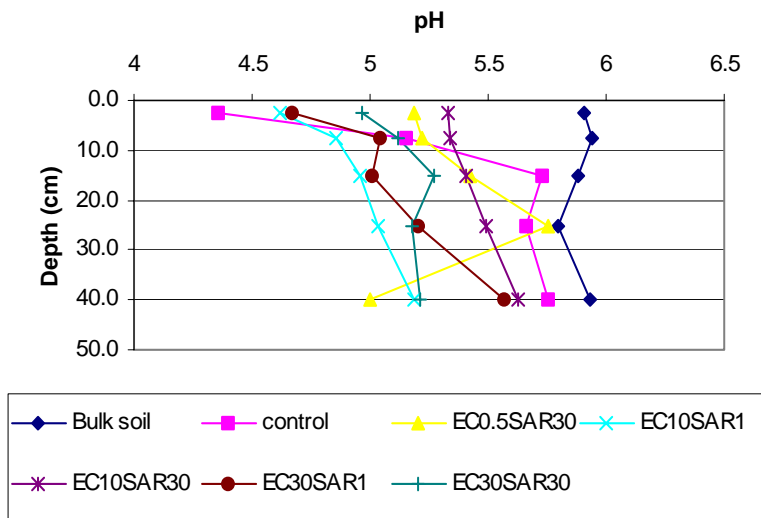


Figure 1. pH of the leached soils after equilibration

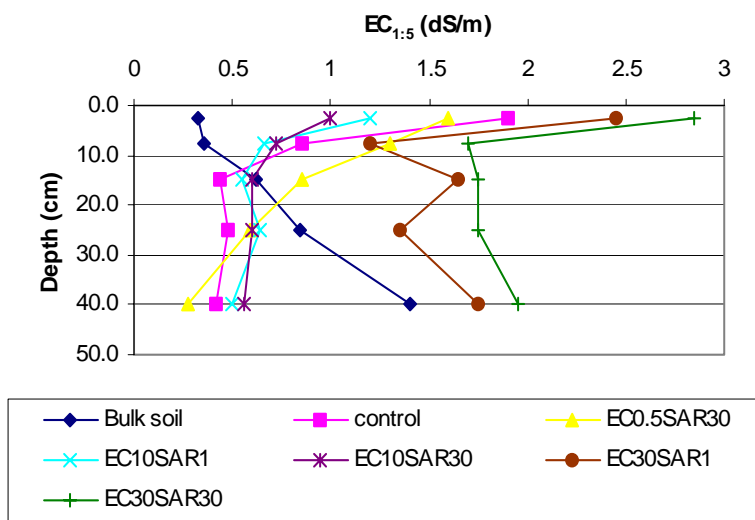
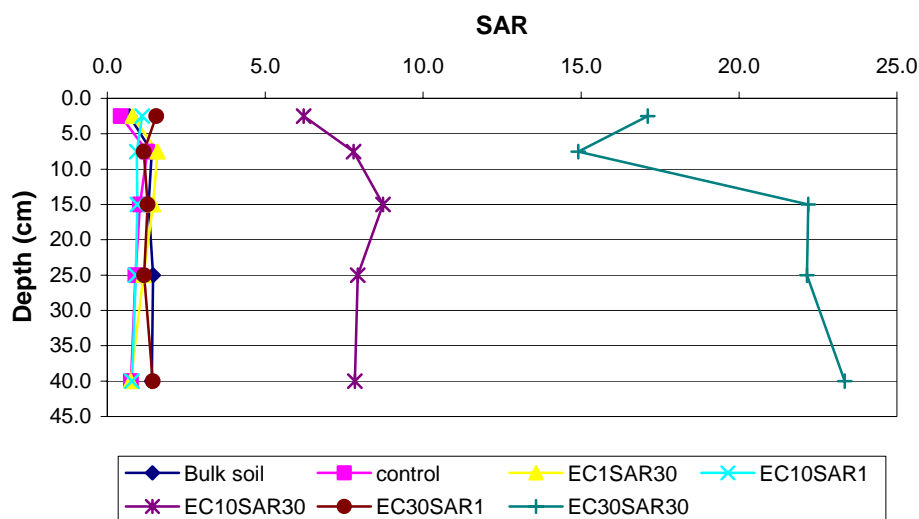


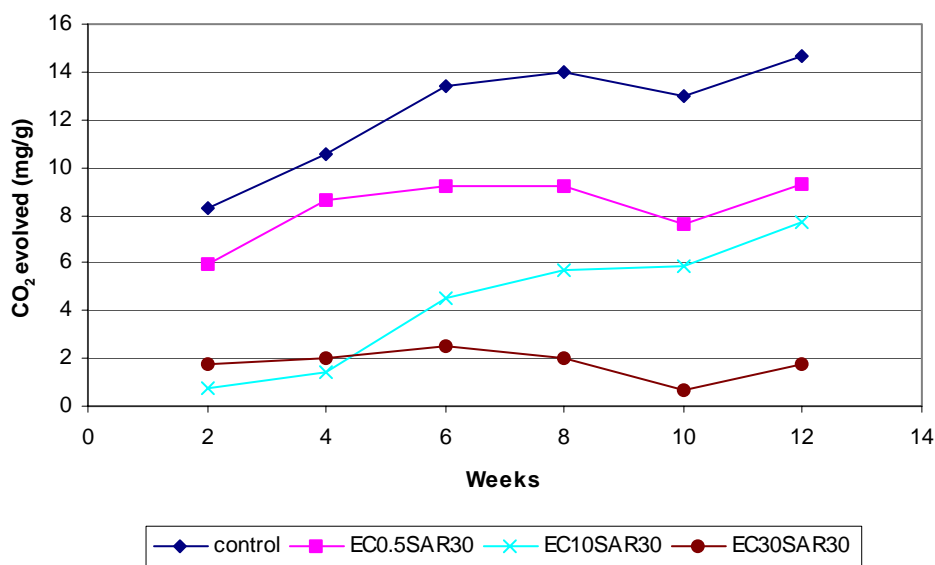
Figure 2. EC of the leached soils after equilibration



**Figure 3. SAR of the leached soils after equilibration**

### Soil Respiration

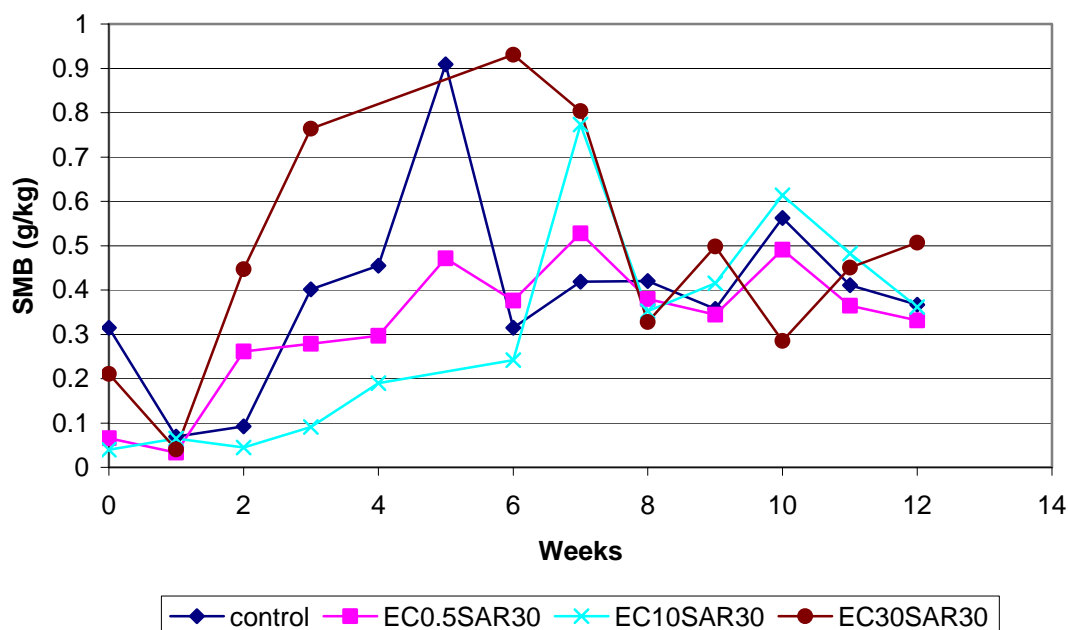
Figure 4 shows the cumulative soil respiration at two week intervals. The control treatment showed the highest rate of respiration over 12 weeks (Figure 4), with the mid-salinity high-sodicity treatment showing the lowest rate of respiration to week 4. The high-salinity high-sodicity treatment showed the lowest rate of respiration after approximately four weeks. The addition of water at weeks 4 and 8 did not appear to affect respiration rates in any of the treatments.



**Figure 4. Cumulative soil respiration over the 12 week incubation under low-salinity low sodicity (control), low-salinity high-sodicity (EC0.5SAR30), mid-salinity high-sodicity (EC10SAR30) and high-salinity high-sodicity (EC30SAR30) treatments.**

### Soil Microbial Biomass

All of the treatments showed a decrease in SMB to at least week 1 in the incubation before increasing. The low-salinity high-sodicity treatment (EC 0.5 SAR 30) appeared to fluctuate around a mean after week 2 (Figure 5). The high-salinity high-sodicity (EC 30 SAR 30) treatment showed the greatest increase to week 6 before declining, while the control treatment showed a similar trend, with the decline occurring at week 5. All treatments appeared to stabilise after week 8.



**Figure 5. Soil microbial biomass carbon over the 12 week incubation under low-salinity low sodicity (control), low-salinity high-sodicity (EC0.5SAR30), mid-salinity high-sodicity (EC10SAR30) and high-salinity high-sodicity (EC30SAR30) treatments.**

## Discussion

The high-salinity high-sodicity treatment had the most dramatic effect on soil biological properties. It caused the largest decrease in respiration and increase in SMB over the incubation period. Sarig *et al.* (1993) found a greater accumulation of SMB under saline irrigation water (EC 5 and SAR 10) compared to regular water (EC 1 SAR 10) over a period of six weeks, attributing the increase to increasing osmotic stress causing an increase in the microbial population. The decline in the SMB at week one is most likely caused by soil disturbance due to sampling. The time lag exhibited by the SMB prior to the increase in biomass was also witnessed by Laura (1976), who attributed the delay to a period of adaptation to the sodic conditions by the microbial population.

The large increase of SMB in the high-salinity high-sodicity treatment may also be due to the solubilisation of organic matter from the addition of a solution high in EC and sodicity. Increasing salinity and sodicity have the potential to increase dissolved organic carbon by dissolving organic matter, initially providing substrate for the microbial population. Jandl and Sollins (1997) have suggested that soluble carbon can provide a large proportion of the microbial substrate, and has the potential to be replenished rapidly by the continued dissolution of organic matter. Thus, processes that increase the solubility of organic matter could conceivably increase the microbial population in the short term.

In conjunction with increased organic matter solubility, high EC solutions, particularly those high in  $\text{Na}^+$  can flood exchange sites on clays, causing organic carbon sorbed on to clay surfaces to be desorbed, also providing additional substrate for the microbial population. Similarly, the addition of salt solutions may also cause the pH of the soil-solution systems to decrease, shown in Figure 1, due to the release of  $\text{H}^+$  from exchange sites. However, the SMB appears to decline and fluctuate about a mean from week 8. While it may indicate that the system is reaching a steady state after the initial disturbance of salinisation and sodication, the decline may also be caused by changes in the osmotic potential due to an increased concentration in salt from the moisture loss, as water was not added to samples analysed for SMB during the incubation period.

Increasing sodicity alters soil physical properties by increasing dispersion and slaking, thus causing microaggregates to disperse. Aggregates have been shown to contain organic matter in their cores (Tisdall and Oades 1982), which is physically protected from decomposition. When conditions occur, which cause aggregates to disperse, the organic material in the cores becomes available for decomposition, which can be reflected in the SMB. Conversely, increasing electrolyte concentration causes soil to flocculate,

offsetting those effects caused by sodicity on a soil's physical properties (Shainberg and Letey 1984). While not confirmed in this study, Nelson *et al.* (1996) found sodicity to increase and salinity to decrease the decomposition of added organic material.

Respiration does not appear to correlate with SMB, although it does not necessarily need to follow the same trends. However, soil respiration provides a measure of microbial activity from actively growing microorganisms and microbial biomass, which consists of active, dormant and dead fractions. Therefore, soil respiration can provide a better measure of the immediate impact of salinity and sodicity in soil on C fluxes than SMB. However, respiration rates can be confounded by factors such as the substrate availability and the composition of the microbial population (Wang *et al.* 2003), which may be altered under different physicochemical conditions, such that the size of the SMB may not reflect biological activities. Similarly, in a study by Laura (1973), the SMB increased under highly sodic conditions due to the increased decomposition of newly available organic matter, while microbial activity decreased, determined from a decline in carbon mineralisation.

### Summary

Increasing salinity and sodicity appears to provide additional substrate for the microbial population in the soil, with the effects due to sodicity more evident than those due to salinity. This has implications for natural resource management and carbon accounting. Where salinisation and sodication of soils is occurring, soil carbon stores are most likely becoming depleted as organic matter becomes solubilised, providing additional substrate for the microbial population, while plant inputs decrease due to stresses caused by increasing salt and Na content of the soil. Additional research is required to verify these results. While these results were obtained under controlled conditions, field trials are necessary to ascertain these impacts over the longer time scales that salinisation and sodication commonly exhibit in the landscape.

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