Dissolved organic matter dynamics and microbial activity in salt-affected soils

A thesis submitted in fulfilment of the degree of
Doctor of Philosophy in Soil Science

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Abstract

Salt-affected soils (comprising saline and sodic soils) contain excessive amounts of salts and cover over 10 % of the world's arable land. They are a serious land-degradation problem because a) salinity causes poor plant growth and low microbial activity due to osmotic stress, ion toxicity and imbalanced nutrient uptake and b) plant growth in sodic soils is limited by poor soil structure and aeration. As a consequence of the poor plant growth, salt-affected soils have low organic matter content. Therefore, to minimise soil degradation, it is important to understand the processes in salt-affected soils particularly those involved in nutrient cycling.

Dissolved organic matter (DOM) is the most labile portion of soil organic matter pools and affects many biogeochemical processes such as nutrient cycling, translocation and leaching, microbial activity and mineral weathering. Even though it only comprises a small portion of the total organic matter (< 1 %), it can be used to determine changes in soil C dynamics prior to detection in the total SOM pool. Salinity and sodicity influence organic matter turnover by affecting the amount of plant material entering the soil as well as the rate of decomposition. While the effects of salinity and sodicity on soil microorganisms and soil organic matter turnover have been studied separately, little is known about their interaction. Therefore the objective of this thesis was to determine the interactive effect of salinity and sodicity on soil microbial activity and dissolved organic matter dynamics in soils of different texture.

Four non-saline and non-sodic soils differing in texture (4, 13, 24 and 40 % clay, termed S-4, S-13, S-24 and S-40) were collected from Monarto near South Australia. The water content resulting in maximum respiration in the soils was

assessed by adjusting the soils to different water content and measuring the respiration for two weeks at 25 ºC. The soils were leached with a combination of NaCl and $CaCl_2$ stock solutions to induce different levels of salinity ($EC_{1:5}$) ranging from 0 to 10 dS m^{-1} and sodium absorption ratio [SAR< 3 (non-sodic) and ≥20 (sodic)] in various experiments. Wheat residue and in one experiment glucose were added as a nutrient source for soil microbes. Respiration was measured continuously throughout the experiments and dissolved organic C, dissolved organic N, total dissolved N (TDN), specific ultra-violet absorbance (SUVA), microbial biomass, electrical conductivity, pH and SAR were analysed at different times during the experiments.

The concentration of dissolved organic carbon (DOC) and nitrogen (DON) is influenced by the type of extractant used. To determine which extractant is the most useful for the experiments described in this thesis, different textured soils were incubated with wheat residue for two weeks and DOC and DON were extracted with water, 0.5M K_2SO_4 or 2M KCl at a 1:5 ratio. Irrespective of soil texture, the concentrations of DOC and DON extracted with 0.5M K_2SO_4 or 2M KCl were more than twice than those extracted with water. Therefore, for the experiments described in this thesis dissolved organic C and N were extracted with a 1:5 soil: water ratio.

In the first experiment, a sand and a sandy clay loam were adjusted to similar EC levels ($EC_{1:5}$ 0.5, 1.3, 2.5 and 4.0 dS m^{-1} in the sand and $EC_{1:5}$ 0.7, 1.4, 2.5 and 4.0 dS m^{-1} in the sandy clay loam) and combined with two sodium absorption ratios: SAR < 3 and 20. The soils were incubated at the water content optimal for microbial activity (6.4 g 100 g $soil^{-1}$ for the sand and 15.6 g 100 g $soil^{-1}$ for the sandy clay loam). This experiment showed that at a similar EC, cumulative respiration was more strongly affected by EC in the sand than sandy clay loam which may have been due to their different water content and therefore, differential osmotic potential. Further, the concentration of DOC, DON and SUVA were significantly higher at EC 0.5 or 0.7 at SAR 20 than at higher EC levels indicating that high SAR in combination with low EC is likely to increase the risk of DOC and DON movement downwards within the soil profile in the salt-affected soils which may cause further soil degradation.

To assess the impact of multiple drying and wetting on microbial biomass and DOC concentration in salt-affected soils, the loamy sand was adjusted to two levels of $EC_{1:5}$ (1.0 and 2.5 dS m^{-1}) and SAR (< 3 and 20) and then exposed to 1-3 drying and rewetting cycles each consisting of 1 week drying and 1 week moist incubation. The flush in respiration after rewetting was lower in saline and saline-sodic soils than in soil without added salt. At the low EC, the solubility of organic matter was higher at SAR 20 compared to SAR < 3 suggesting that loss of C via DOC leaching may be increased in sodic soils, irrespective of the drying and wetting cycles.

For the study on the effect of sodicity (SAR < 3 and >20) and salinity ($EC_{1:5}$ 1.0 and 5.0 dS m^{-1}) on DOM sorption, four soils of different texture (4, 13, 24 and 40 % clay) were shaken overnight at 4°C with solutions containing 0, 23, 43, 58, 86 and 128 mg C L^{-1} extracted from wheat residue. Sorption was calculated from the difference between initial DOM concentration and that after shaking. The experiment showed that high SAR (>20) only decreased DOC sorption at low EC (1.0 dS m^{-1}) which can be explained by the high electrolyte concentration causing flocculation of DOC at high EC (5.0 dS m^{-1}). DOC sorption was greatest in the soil with 24 % clay across all concentrations of DOC added whereas DOC sorption did

not differ greatly between the soils with 4, 13 and 40 % clay which suggested that sorption of DOC was not directly related to clay concentration, but instead was a function of CEC (highest in the soil with 24 % clay) and concentration of Fe and Al (highest in the soils with 4 and 13 % clay).

The study to examine how different forms of C (wheat straw and glucose, added at 2.5 mg C g^{-1}) with and without added inorganic N affect the response of microbial activity and biomass to increasing $EC_{1:5}$ (0.1 to 10 dS m^{-1}) showed that respiration and microbial biomass C decreased with increasing EC, but the decrease was smaller with glucose than with wheat straw. Addition of N to glucose and wheat straw to bring the C/N ratio to 20 significantly decreased cumulative respiration and microbial biomass C at a given EC. Thus, addition of easily available C can enhance microbial tolerance to salinity whereas high N addition rates may have an adverse impact on microbial activity.

In the last experiment, salt was added to the four soils to achieve EC values between 0.4 and 5.0 dS m^{-1} with two levels of SAR : < 3 and >20 together with the optimal water content for microbial activity, which resulted in three osmotic potential ranges in all four soils (> -0.55, -0.62 to -1.62 and -2.72 to -3.0 MPa). This experiment confirmed that salt stress has similar effects on soil microbes in soils of different texture and water content when expressed as osmotic potential whereas the soil microbes appear to be more sensitive to salts in lighter textured soils when EC is used as measure of salinity. Therefore, osmotic potential needs to be considered when comparing saline soils with different water holding capacity.

The results of the study showed increasing salinity adversely affects microbial activity and therefore increases DOC and DON concentration, whereas an increased

DOC and DON concentration in response to sodicity was observed only at low EC. Thus, both salinity and sodicity can result in increased loss of C and N through high concentration of DOM in leachates which may lead to further soil degradation and reduce C sequestration. The study also confirmed that soil texture and water content play an important role in determining the response of microbes to salt stress due to their effect on the salt concentration in the soil solution. Therefore, osmotic potential is a better measure for evaluating stress to microbes in the salt-affected soils than EC. Further, the study also highlighted that addition of a readily available and easily decomposable source of energy improves the ability of microbes to tolerate salinity whereas N addition has no or a negative impact on microbial activity and growth.

Declaration

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