Modelling organic carbon turnover in salt-affected soils

A thesis submitted to The University of Adelaide in fulfilment of the requirements for the degree of Doctor of Philosophy

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Soils

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Dedicated to my parents and wife

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ABSTRACT

Salinity and sodicity are major constraints for crop production in arid and semi-arid regions of the world. Salt-affected soils cover 6.5% of the total land area of the world. Since the global soil carbon (C) pool is greater than the atmospheric and biotic pool combined, changes in soil organic matter content will affect atmospheric carbon dioxide (CO_2) concentration. Therefore it is important to understand soil organic carbon (SOC) dynamics. Soil organic carbon models, which have been successfully validated for non-saline soils, are important for estimation of past and future SOC contents and for evaluating management effects on SOC. However, it was unclear if they accurately predict CO_2 emission/SOC stocks in salt-affected soils. In this work, an integrated approach using remote sensing, incubation experiments, modelling and geographical information system was used to simulate SOC dynamics in salt-affected soils at field and regional scale in the past, present and the future.

Satellite imagery was used to map soil salinity and select soil sampling sites in two climatically distinct regions which also differ in cause of salinity: Kadina, South Australia and Muktsar district (Punjab), India. High resolution multispectral satellite imagery (Quick bird, spatial resolution 0.6 m) was used to map salinity (~1:10000 scale) in an agricultural area around Kadina, South Australia where salinity associated with ground water or an impermeable subsoil is wide-spread. Resourcesat-I (spatial resolution 23.5 m) was used for mapping salinity on a 1:50000 scale in Muktsar (Punjab), India where salinity is induced by irrigation. Unsupervised classification of the Quick bird imagery (September, 2008) covering the study area in South Australia (hereafter called Australia) allowed differentiation of severity levels of salt-affected soils, but these levels did not match those based on electrical conductivity (EC) and sodium adsorption ratio (SAR) measurements of the soil samples, primarily because the expression of salinity was strongly influenced by paddock-level variations in crop type, growth and prior land management. Segmentation of the whole image into 450 paddocks and unsupervised classification using a paddock-by-paddock-approach resulted in a more accurate discrimination of salinity with image derived salinity classes correlated with EC but not with SAR. For the Indian site (hereafter called India),

Resourcesat-I LISS-III data of April 2005, October 2005 and February 2006 was visually interpreted for variation in spectral properties. The map of salt-affected soils was generated after integration of ground and laboratory data with delineated land use units from the satellite data. On the basis of land use and soil types, 120 (59 salt-affected and 61 non-salt-affected) and 160 (70-salt-affected and 90-non-salt-affected) soils were collected from 0-0.30 m depth from the Indian and Australian sites, respectively.

Salt-affected soils occur in dry climates and often contain calcium carbonate ($CaCO_3$) particularly at pH > 7.5. Therefore, using CO_2 emission as a measure of microbial activity and SOC decomposition in these soils is problematic, but an experiment involving addition of 2% wheat residues and varying the rate of calcium carbonate added to a non-calcareous soil showed that CO_2 emission from salt-affected soils was not affected by $CaCO_3$ addition in the presence of residues.

It has been suggested that the salt concentration in the soil solution (osmotic potential) is a better parameter than the EC of a soil suspension to estimate the salinity effect on plant growth. Therefore, an incubation experiment with four soils differing in texture and amended with sodium chloride (NaCl) was conducted to assess the effect of soil texture and osmotic potential (O_s, calculated from EC and water content) on CO_2 release. The results of this study showed that, compared to saline soils from the field, the decrease in CO_2 release was greater in these soils suggesting that the sudden increase in salinity leads to overestimation of the salinity effect compared to saline soils in the field where salinity increases gradually. The relative decrease in respiration was less when plotted against O_s than if plotted against EC.

To investigate the importance of salinity compared to other soil properties in soils from a salt-affected landscape, CO_2 emission from the soils of India and Australia with a wide range of EC and SAR with 2% (w/w) mature wheat residue was measured over 120 days at constant temperature and soil water content. Cumulative CO_2 emission from unamended and amended soils was related to soil properties by stepwise regression models. Carbon dioxide release in salt-affected landscapes is affected by EC, C availability (size of C pools) and clay content. Electrical conductivity had a negative impact on CO_2 release in soils of India and Australia, which shows the universal effect of salinity on CO_2 release, irrespective of climate and origin of salinity.

Therefore, there is a need to add a decomposition rate modifier for salinity in the SOC models for accurate prediction of SOC dynamics and CO_2 release from salt-affected soils.

The Rothamsted Carbon Model (RothC) was modified to take into account the reduced plant inputs into salt-affected soils. Plant inputs were calculated based on a generalised equation from the literature. The decomposition rate modifier for salt-affected soils was based on the comparison of measured and modelled CO_2 emissions from wheat residue amended soils of India and Australia. The modelled CO_2 emissions were higher than measured CO_2 emissions. In order to match the measured and modelled CO_2 emissions, rate modifiers ranging from 0.2-1 were introduced in the model. After accounting for the laboratory effect due to soil disturbance, the impact of salinity (calculated using O_s) or sodicity (measured as SAR) on the rate of decomposition was calculated. A significant positive relationship was found between decomposition rate modifier and O_s whereas SAR had no effect. Therefore, a decomposition rate modifier due to salinity (as a function of O_s) was introduced into RothC.

The RothC with the plant input modifier and decomposition rate modifier was used to estimate past SOC content when saline soils were non-saline and future SOC content. These simulations were performed for the Indian and Australian sites. The results showed that the modelled past SOC when the soils were non-saline was higher than measured SOC of saline soils; thus these soils have lost SOC (31 t ha^{-1} for India and 55 t ha^{-1} for Australia). On the other hand, simulations with the decomposition rate modifier only, without taking into account the reduced plant input, suggest that SOC of saline soils has increased since they became saline. Since SOC in saline soils is lower than in non-saline soils, this shows that in order to accurately model SOC stocks in saline soils, both reduced plant inputs and reduced decomposition rate have to be taken into account. Overall SOC content was more strongly affected by reduced plant inputs than by reduced decomposition rates. In addition, future SOC stocks of India and Australia were simulated with and without modifiers from 2009-2100. In saline soils of both regions, the simulation of SOC without modifiers showed that, compared to the present SOC content, SOC would decrease by ≤15% by the year 2100, whereas simulations with decomposition rate modifier and plant input modifier indicate that SOC would decrease by 39% for the Indian site and by 29% for the Australian site.

The key findings from the research are:

I. High resolution multispectral imagery with paddock-by-paddock approach allowed accurate mapping of different levels of salinity severity.

II. In saline soils, osmotic potential is a better measure to assess the impact of salt on microbial activity than EC, particularly when comparing soils of different texture.

III. In soils from salt-affected landscapes, salinity and reduced carbon availability determine CO_2 emission.

IV. Two novel approaches were developed: (a) calculation of a decomposition rate modifier from incubation experiments after taking into account the laboratory effect and (b) calculation of past SOC content when saline soils were non-saline.

V. The predictions of SOC stocks from saline soils have been overestimated by not taking into account the negative effect of salt on decomposition rate and plant inputs.

VI. For realistic modelling of SOC stocks and turnover in saline soils, both reduced decomposition rate and reduced plant inputs need to be considered.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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