Capturing carbon in Australian soils: Potential and realities

J.A. Baldock[A], J. Sanderman[B] and R. Farquharson[B]

[A]Sustainable Agriculture Flagship\CSIRO Land and Water, Urrbrae, SA 5064, Australia, Email jeff.baldock@csiro.au
[B]Sustainable Agriculture Flagship\CSIRO Land and Water, Urrbrae, SA 5064, Australia.

Abstract
An interest exists to enhance the amount of carbon contained in Australian soils because of the beneficial impacts on both soil productivity and atmospheric concentrations of greenhouse gases. There is no doubt that Australian soils have the capacity to capture additional carbon by altering current management practices. However, much debate remains over the potential rate and magnitude of carbon capture. It is unlikely that capturing carbon within soil will offset Australia's net greenhouse gas emissions, but it is likely that soils can contribute to reducing emissions within a broader set of strategies. A review of Australian research trials comparing traditional agricultural management practices with practices designed to retain addition carbon has indicated that, irrespective of the management practices applied, soil carbon values have continued to decline under agricultural production. However, the extent of SOC reduction was reduced under more conservative carbon friendly practices. This would result in an avoided emission, when compared to the business as usual scenario, rather than a net sequestration of carbon from the atmosphere. In an effort to extend our understanding of the magnitude of soil carbon change under different land use/management practices at a regional scale, a national soil carbon project has been recently established. This program will sample soils from the major combinations of soil and land use/management practices within defined regions across Australia. Land use/management impacts on differences in both the amount and composition of soil carbon will be defined.

Key Words
Measurement, modelling, scaling, accounting.

Why are we interested in changing the amount of carbon captured in soil?
Current interest in enhancing the amount of organic carbon captured in Australian soils exists for the following two reasons: the positive influence that soil organic carbon (SOC) has on a range of soil properties, and the potential to reduce Australia's net greenhouse gas emissions. SOC contributes positively to a variety of soil biological, chemical and physical properties and processes (Figure 1). Strong interactions (represented by the grey arrows) can exist between these different functions. For example, the biological function of providing energy for microbial activity may also result in improved structural stability and create organic materials that contribute to cation exchange and pH buffering.

A main determinant of agricultural productivity over much of Australia is the availability of water. Future predictions of climate change suggest that much of Australia's current agricultural land will be become warmer and drier. Under such scenarios, an enhanced capacity of soils to store plant-available water will be critical to maintain productivity. The application of pedotransfer functions derived by da Silva and Kay (1997) to the 0-10 cm layer of 80 Red Chromosols from South Australia indicate that increasing soil organic carbon content by 1% of the total soil mass (e.g. from 0.7% to 1.7%) would increase plant-available water holding capacity by 2 to 4 mm with the effect diminishing with increasing soil clay content (Figure 2). Beneficial changes in soil properties such as water holding capacity, and others depicted in Figure 1, provides the impetus to enhance the capture of carbon in soils for reasons beyond reducing net greenhouse gas emissions and carbon accounting purposes.

Do Australian soils have a capacity to capture additional carbon?
Soil provides a significant reservoir of organic carbon in Australia, 19 Pg C in the 0-30 cm soil layer (Grace *et al.* 2006) with an annual flux of 0.18 Pg C y^{-1} (Barrett, 2002), relative to the size of Australia's net greenhouse gas emissions, 0.15 Pg C y^{-1} (National Greenhouse Gas Inventory May, 2009). An annual 0.8% increase in the amount of carbon stored in the 0-30 cm layer across all Australian soils would offset Australia's net emissions. However, of the 769Mha of total land area within Australia, only 469 Mha are used for agriculture and of that, only 49.6 Mha are actively managed (24.6 for grazing of modified pastures and 25 for dryland cropping) (Bureau of Rural Sciences, 2001/2002). If the area available for capturing

carbon is limited to managed agricultural lands (49.6 Mha) and it is assumed that these lands, on average, contain three times more carbon per ha than other lands, an annual increase in soil carbon across all managed agricultural lands equivalent to 4.6% of current values would be required to offset all of Australia's emissions. This would be equivalent to an average increase in SOC stocks of 3.0 Mg C ha^{-1} y^{-1}. Given that estimates of average net primary productivity vary between 0.9 and 4.3 Mg C ha^{-1} (Roxburgh *et al.* 2004), it would appear unlikely that enhancing the capture of carbon within soils could completely offset Australia's net greenhouse gas emissions.

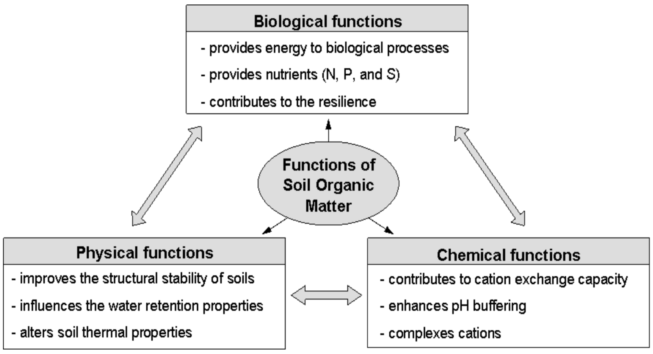

Figure 1. Functions performed by organic matter present in soils.

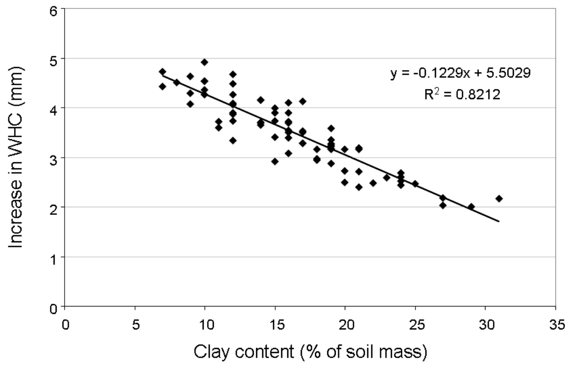

Figure 2. Magnitude of the estimated increase in soil water holding capacity (WHC) induced by increasing soil organic carbon content by 1% of total soil mass for red-brown earths of the mid-north of SA.

It remains possible, however, that capturing additional carbon within soil or reducing the extent of carbon emission from soil by altering land use and/or agricultural management practices could contribute significantly to a broad strategy aimed at reducing Australia's net greenhouse gas emission. This is particularly evident for cultivated soils where significant reductions in soil carbon can occur due to the initiation of agricultural production. Gifford *et al*. (1990) estimated that 39% of the native condition soil carbon stock has been lost over the 1860-1990 period and Guo and Gifford (2002) suggested that conversion of native forest and pasture to cropland reduced SOC stocks by an average of 42% and 59%, respectively. Such management induced reductions in soil carbon suggest that a capacity exists to recapture at least a portion of the carbon lost on initiating cultivation. Lal (1999) suggested that maximum levels of soil carbon under agricultural production would equate to 60-75% of that present under native condition.

Based on these findings and indications, it can be concluded that soil carbon does have a potential place in emissions reduction but it will not provide the longer term solution on its own. Economic considerations related to implications on farm profitability will need to be investigated along with possible incentive payments in order to encourage adoption and effect significant change in Australian soil carbon stocks.

Management practices that can enhance SOC

A review of Australian field trial data available in peer reviewed journals has been completed as part of an ongoing project with the Australian government Department of Climate Change. In this review its was found that on average the absolute rate of change in soil carbon (defined as the change calculate using data collected temporally from individual sampling locations) was negative across a range of management practices considered to capture additional carbon within soils (Figure 3a). This finding suggested that, across the soils and management practices investigated, soil organic carbon was decreasing on average. However, it was also evident from this review, that relative to more traditional less soil carbon 'friendly' practices, soils under agricultural management practices considered capable of capturing additional carbon reduced rates of loss that lead to higher relative soil carbon contents even though on average declines in absolute terms were obtained (Figure 3b). As a result, the implementation of more carbon 'friendly' management practices appears to be avoiding emissions compared to the business as usual scenario.

Developing a national approach to defining soil carbon dynamics

The National Carbon Accounting System (NCAS) in Australia has adopted a Tier 3 approach to account for management impacts on soil carbon. A soil carbon simulation model based principally on a variant of the RothC soil carbon model (Jenkinson, 1990; Jenkinson *et al.* 1987) has been formulated. Variations from the original RothC model include the substitution of conceptual model pools with measurable pools (Skjemstad *et al.* 2004) and the inclusion of soil N cycling capabilities through assignment of C/N ratios to the various soil carbon fractions in a manner similar to that used in the Century soil carbon and nutrient cycling model (Parton *et al.* 1987; Parton *et al.* 1988). NCAS can be parameterised with measured values to define carbon dynamics at an individual point or a combination of default values and spatial data layers can be used to integrate carbon cycling over defined land areas. The latter approach is used to define the impact of land use and land use change on soil carbon for Australia's national greenhouse gas inventory.

A national soil carbon research program (SCaRP) has been established for Australia to define regional impacts of land use and management practices on the quantity of carbon present in selected agricultural soils. This program has adopted a consistent sampling and analytical methodology to ensure that directly comparable data sets are collected across the country. SCaRP will provide estimates of the actual distribution of soil carbon and its composition (attribution to the soil carbon fractions used in NCAS) and allow for the identification of management practices capable of enhancing soil carbon on a regional basis. A series of traditional (Figure 4) and more modern multivariate statistical approaches will be applied to the collected data to identify management impacts on soil carbon as well as some of the underlying mechanisms that account for the differences. Such information will be used to inform NCAS and identify regional combinations of soil type and management that optimise soil carbon accumulation. The program is also seeking to define the role that introducing perennial pastures into previously annual pasture systems can have on increasing soil carbon and to develop a cost effective methodology for quantifying soil carbon content and its allocation to fractions used to parameterise NCAS with a defined level of confidence in derived values.

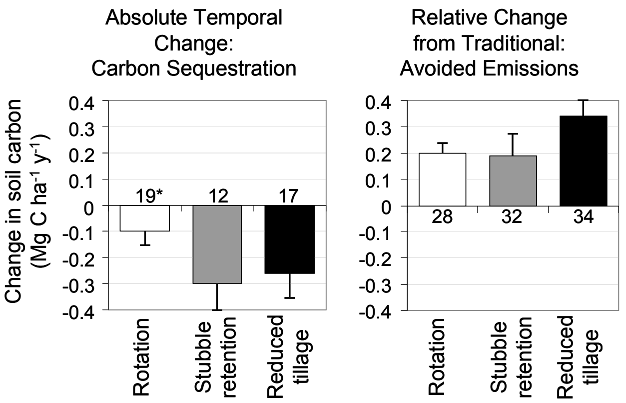

Figure 3. (a) Average absolute rate of soil carbon change under 'carbon soil carbon friendly' management practices and (b) relative difference in rates of soil carbon change between traditional and 'soil carbon friendly' management practices obtained in a review of Australia data appearing in peer reviewed publications. (* values indicate the number of studies included).

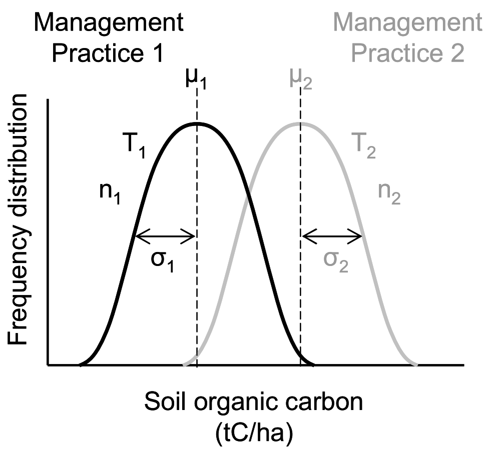

Figure 4. Schematic representation of one approach (the traditional statistical approach) to be taken within SCaRP to define the influence of agriculture (land use and management practices) on soil carbon.

References

Barrett DJ (2002) Steady state turnover time of carbon in the Australian terrestrial biosphere. *Global Biogeochemical Cycles* **16**.

Bureau of Rural Sciences (2001/2002). Land use of Australia, Version 3. http://adl.brs.gov.au/mapserv/landuse/docs/2001_02_Nat_Luse_Summary_Stats.pdf

da Silva AP, Kay BD (1997) Estimating the least limiting water range of soils from properties and management. *Soil Science Society of America Journal* **61**, 877-883.

Gifford RM, Cheney NP, Noble JC, Russel JS, Wellignton AB, Zammit C (1990) Australian lan use, primary production of vegetation and carbon pools in relation to atmospheric carbon dioxide concentration. In 'Australia's Renewable Resources: Sustainability and Global Change (Bureau of Rural Resources Proc 14)'. (Eds RM Gifford, MM Barson) pp. 151-188. (Australian Government Publishing Service: Canberra).

Grace PR, Post WM, Hennessy KJ (2006) The potential impact of climate change on Australia's soil organic carbon resources. *Carbon Balance and Management* **1**, 14-24.

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. *Global Change*

Biology **8**, 345-360.
Jenkinson DS (1990) The turnover of organic carbon and nitrogen in soil. *Philosophical Transactions of the Royal Society B: Biological Sciences* **329**, 361-368.
Jenkinson DS, Hart PBS, Rayner JH, Parry LC (1987) Modelling the turnover of organic matter in long-term experiments at Rothamsted. *Intecol Bulletin* **15**, 1-8.
Lal R (1999) Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. *Progress in Environmental Science* **1**, 307-326.
Parton WJ, Schimel DC, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* **51**, 1173-1179.
Parton WJ, Stewart JWB, Cole CV (1988) Dyamics of C, N, P and S in grassland soils - a model. *Biogeochemistry* **5**, 109-131.
Roxburgh SH, Barrett DJ*, et al.* (2004) A critical overview of model estimates of net primary productivity for the Australian continent. *Functional Plant Biology* **31**, 1043-1059.
Skjemstad JO, Spouncer LR, Cowie B, Swift RS (2004) Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools. *Australian Journal of Soil Research* **42**, 79 - 88.