Development of a soil carbon benchmark matrix for central west NSW

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Abstract
The development of a spatial framework for soil carbon data is described. The theoretical basis is a general conceptual model for soil carbon in combination with the general soil carbon equation used in most soil carbon models. A general set of soil, climate, land management and landform factors that influence soil carbon levels are described. How existing sources of information including soil maps, climate data and land management data can be used to develop a soil carbon matrix is briefly described. Some of the advantages of developing this soil carbon matrix are explained.

Key Words
Spatial framework, soil carbon potential, land management.

Introduction
Soil carbon is the prime determinant of biological soil condition and globally is the largest component of terrestrial carbon. Soil carbon is impacted by climate, soil type, land use and land management practices. Practices that increase soil carbon improve soil condition and remove atmospheric carbon and soil carbon storage across NSW landscapes have the potential to contribute significantly to climate change mitigation and climate change adaptation. However, there is an urgent need to interpret and combine existing data into a comprehensive spatial framework to track and predict soil carbon levels across the State. This spatial framework can be based on a matrix of soil x climate x land use x land management combinations that are representative of each region. This soil carbon matrix will provide a mechanism for assessing the impacts of land use and land management change across regions. It will provide capacity to rapidly estimate expected critical or benchmark soil carbon levels for different locations throughout NSW. The matrix will potentially provide a capacity to apply Market Base Instruments as a natural resource management tool and even possibly a tool for soil carbon trading. The difficulty is in populating the soil carbon matrix. This paper outlines some of the problems and possible methodologies that can be applied to develop such a soil carbon matrix for two catchments in central west NSW.

Developing the spatial matrix for soil carbon - theoretical basis
Soil organic carbon (SOC) levels in soils can be described broadly by the following set of equations.

$$\text{SOC} = f\,(\text{soil, climate, land use/land management practice, landform, time}) \qquad 1$$

which is a conceptual model.
In addition use can be made of the general soil carbon equation (Dalal and Chan 2001).

$$\text{SOM}t = \text{SOM}_0 \exp(-kt) + \text{A}/k\,[1 - \exp(-kt)] \qquad 2.1$$

Where SOM_0 and SOM_t are the SOM contents initially (t = 0), and at a given time, t, A (mass of SOM per unit area) is the rate at which organic matter is returned to the soil; and k (reciprocal of time) is the rate of loss of SOM or the rate of decomposition. The value of k will vary with the nature of the organic matter and the amount of soil carbon in each of the carbon pools or fractions.
The values of A and k will vary with the range of factors as described in Table 1. The soil and climate factors will affect the values of A and k in these equations. Position in the landscape will also affect A and k by affecting the accumulation and redistribution of water, nutrients, sediments and organic matter. Soils on ridges and upper slopes will tend to lose soil and organic matter which will tend to accumulate on lower slopes and in depressions. Generally soils in lower slope positions will tend to have a wetter moisture regime for longer. In turn land management practices have a very large impact on A and k and can be used to manipulate A and k to bring about changes in soil organic matter and soil carbon.

Soil organic matter is heterogeneous and composed of different fractions or pools. A more accurate description of changes in soil carbon is then given by:

$$SOMt = SOM_1 \exp(-k_1 t) + A_1/k_1 [1 - \exp(-k_1 t)] + \ldots\ldots\ldots\ldots\ldots\ldots + \ldots\ldots\ldots\ldots + SOM_n \exp(-k_n t) + An/k_n [1 - \exp(-k_n t)] \quad \ldots\ldots\ldots\ldots 2.2$$

Where the terms represent the amount of soil organic matter in a given fraction in the soil (SOM_n), the amount of organic matter in a given fraction added to the soil (A_n) and the decomposition constants for the fractions k_n.
Land management practices can change the amount of soil carbon in each of the pools or fractions. For example it is likely that organic matter derived from trees and woody native vegetation is likely to have more soil carbon in the more resistant soil carbon fractions. There are some suggestions that this also occurs with organic matter derived from perennial grasses but this is currently under investigation.

Equation 1 can be used to estimate how the values of SOM_0, A and k will vary across the landscape with soil type, climate and changes in land management practice and land management activities. Table 1 provides a list of the factors that can influence the values of A and k in equations 2.1 and 2.2.

Developing the spatial matrix for soil carbon - steps
The steps to developing a spatial matrix for soil carbon will include the following.

A. Determining combinations of soils and climate that have an equivalent soil carbon potential. These combinations can be termed soil carbon zones for convenience and within these specified land management practices will have a defined soil carbon potential. For practical purposes, the soil carbon potential is defined as the amount of soil carbon that can be accumulated to 30 cm at long term equilibrium under a specific land management practice. In defining these combinations some initial assumptions will be made based on the factors in Table 1.

B. Using existing soil landscape maps and climate information (SILO Database and FullCAM climate data) the soil carbon zones will be spatially delineated using GIS layers. The existing soil landscape maps can potentially provide the soil information identified in Table 1, while the climate data sources can easily provide the climatic data. The land management data required for each region is more difficult to obtain. Use can be made of the review by Valzano *et al.* (2005). Several monitoring programs and good local knowledge from local advisory and land resource officers will be of great value in obtaining useable land management data.

C. The soil carbon potentials for different land management practices within the soil carbon zones will be estimated using data from a range of sources including:
a. Experimental and high quality monitoring soil carbon data (DECCW MER Program), including reviews (Valzano *et al.* 2005; Murphy *et al.* 2003).
b. Soil carbon data from routine soil testing and general monitoring soil carbon data (CMA and landholder data)
c. Modelling of soil expected carbon levels (FullCAM).
d. General expert knowledge estimates.

The outcome will be to populate a spatial matrix of benchmark soil carbon values that can be used as a basis for evaluating the soil carbon status of soils across the region. An example of how the results can be presented is shown in Figure 1 for one soil carbon zone.

Table 1. List of factors that influence the values of A and k in Equations 2 and 3. These factors will affect the rates of addition of soil carbon to the soil and the rates of decomposition of soil carbon. These factors will also influence how soil carbon is distributed between the different soil carbon fractions in the soil.

Soil factors /landform	Climatic factors	Land use and land management practices	
Landform Accumulation of soil carbon in lower slopes; More moisture in lower slopes; Deeper soils on lower slopes; Clay content / texture Soil nutrient levels Nitrogen; pH – soil acidity; Alkalinity; Phosphorus; Sulfur; Soil structural condition Water holding capacity; Surface soil sodicity; Subsoil sodicity; Compaction; Erosion; Soil depth Profile drainage Periods of free water; Periods of anaerobic conditions; Salinity Subsoil salinity; Surface salinity; Scalding.	Moisture regime Rainfall; Evaporation; rainfall /evaporation ratio; Temperature regime Annual average minimum temperatures; Annual average maximum temperatures; Temperature distribution through the year; Wind Wind erosivity;	Biomass production Fertilisation and agronomic management which can increase biomass production; more plant residue; Nutrient management critical, also acidification;, grazing management critical; Soil cultivation and tillage Results in greater soil aeration, loss of moisture; More rapid decomposition; decreased organic matter levels; Aggressive tillage exposes "protected" soil carbon; Lengthy fallow periods reduce plant biomass input to soils and therefore reduce overall organic matter levels; Burning – stubble or residues Releases the carbon stored in these residues; Oxidises carbon stored in the soil fire though can also add resistant char to the soil; Erosion from bare soil surfaces Can remove organic matter in water- or wind-borne soil particles; No-till, direct drill cropping practices (conservation type) – Has been shown to increase soil carbon by modest amounts; Needs to be part of a complete crop management package with fertiliser use, controlled traffic etc; Many other agronomic, economic and soil condition benefits.	Perennials pastures – Re-establishment and appropriate management of perennial components of farming systems can also enhance soil organic matter content; Re-establishment of perennial pastures (even as a component of a farming rotation) has been shown to increase soil organic matter in this environment more than any other farming technique; Careful management of these pastures can greatly enhance soil organic matter contents; Trees, native vegetation Soil organic matter is invariably higher under trees in this environment compared with other land-uses; Retaining or re-establishing trees in the region should be encouraged although trade-offs with agricultural production must be considered; Applications of manures, organic materials, composts, biochar These have been shown to significantly increase soil carbon. However, although on small horticultural plots, these applications might be an economic alternative, they usually require large quantities of application and this might be of limited utility in broad-acre farming.

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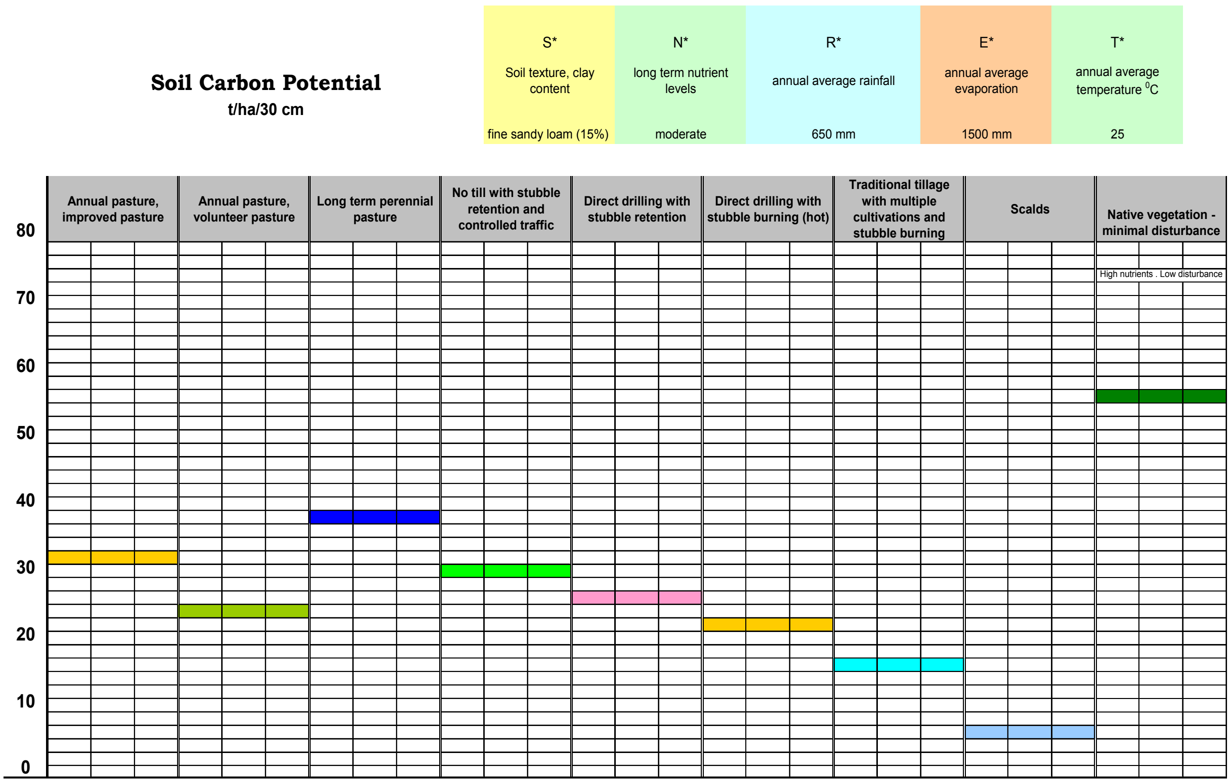

Figure 1. Possible representation of the soil carbon potentials for a range of land management options for a single soil carbon zone in Central West NSW. This is based on some soil carbon data for the Red Chromosol cropping belt within the Central West.

Conclusion

The concept of the soil carbon benchmark matrix is a useful tool to provide a spatial framework to organise existing and future soil carbon data. It has a sound theoretical basis and a range of practical applications for understanding the science and management of soil carbon.

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