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Opportunities to sequester carbon in soil: management of perennial pastures

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Abstract:
Carbon sequestration in soil presents an opportunity for agricultural systems to be a net sink, rather than source of atmospheric carbon. It has been suggested that grazing and nutrient management of perennial pastures are the main drivers of carbon sequestration in agricultural soils. This paper outlines results from investigations into carbon concentration and carbon stock under perennial pastures in south-eastern NSW. Forty eight sites were sampled at regular depth intervals to 0.70 m. Comparisons included: i) soil type (basalt- *vs* granite-derived), ii) climate (summer dominant *vs* equiseasonal rainfall), iii) pasture type (native *vs* introduced perennial pasture), iv) grazing management (continuously vs rotationally grazed) and v) soil fertility. There was a significant difference in the mass of C in soil due to soil type (P <0.001) and climate (P = 0.008). Basalt derived soils had an average of 159 Mg C ha^{-1} to 0.70 m, deep granite-derived soils had 76 Mg C ha^{-1} and shallow granite-derived soils had 43 Mg C ha^{-1}. Pasture type did not significantly influence the mass of C in soil and soil fertility and grazing management explained some of the variation in C mass.

Key words: carbon saturation, carbon stock, climate, pasture, soil fertility, grazing management

Introduction

Before entering into a scheme where soil C is traded, it is important to understand what is driving the potential for soil to sequester carbon. The mass of C or 'carbon stock' in soil is influenced by soil type, climate, vegetation and land management (Blanco-Canqui and Lal, 2008, Lal, 2004, Sparling, 1992). The opportunity to sequester C in agricultural soils through appropriate management depends on the sensitivity of C stocks to these factors.

To increase the C stock, inputs such as biomass and C-rich organic amendments need to be greater than losses such as decomposition of organic matter (OM) by micro-organisms and soil erosion. Soil physiochemical properties and climate influence soil moisture, nutrient concentration and temperature, thereby driving herbage mass production and microbial activity (Blanco-Canqui and Lal, 2008, Lal, 2004, Six et al., 2002, Sparling, 1992). Clay particles and soil aggregation can limit micro-organism access to OM; physically protecting it from decomposition and chemically protect OM by sorbing and complexing organic molecules (Bird et al., 2003, Conant et al., 2003, Six et al., 2002, West and Six, 2007).

It has been suggested that well-managed, perennial pastures may maximise C sequestration in agricultural soils (Chan et al., 2010, Lal, 2004, Post and Kowon, 2000, Sanderman and Baldock, 2010). Compared to most agricultural crops, perennial pastures produce more below ground inputs with greater soil persistence (Sparling 1992). This paper examines the variation in C concentration and C stock (Mg C ha^{-1}) in soil under perennial pastures in south-eastern NSW. Comparisons include: i) soil type, ii) climate, iii) pasture type, iv) grazing management and v) soil fertility.

Methods

Site location

Forty eight sites were located across the Monaro and Boorowa regions in south-eastern NSW (Figure 1). The Monaro region has a summer dominant rainfall pattern with an average annual rainfall of 500mm. The Boorowa region has an equiseasonal rainfall pattern with an average annual rainfall of 610mm. In the Monaro region, both granite derived duplex soils (Kurosols and Chromosols, n= 18) and basalt derived gradational soils (Dermosols and Ferrosols, n= 12) were sampled in winter 2009. Both deep granite derived soils (n= 12) where the C horizon was deeper than 0.50 m, and shallow granite derived soils (n= 6) where the C horizon was within 0.50 m of the soil surface were sampled. In the Boorowa region, (deep) granite derived duplex soils (Kurosols and Chromosols) were sampled (n= 18) in autumn 2010.

Where possible, sites with the same soil and landscape attributes were paired to include a native and introduced perennial pasture within 100 m of one another. Only native pastures were sampled on shallow granite derived soil as introduced pastures are uncommon on this soil type. Introduced pastures were established before 1998 and were typically phalaris (*Phalaris aquatica* L.) and cocksfoot (*Dactylis glomerata* L.). The native pasture sites had never been cultivated and were typically composed of danthonia (*Austrodanthonia*), microlaena (*Microlaena stipoides*), stipa (*Austrostipa scabra*) and also in the Monaro region poa tussock (*Poa labillardierei*). Both pasture types included exotic annual species such as subterranean clover (*Trifolium subterraneum*). Grazing management varied between (but not within) pairs; with some sites being continuously grazed without rest ("continuous grazing") and other sites being grazed and then rested for a period of time ("rotational grazing").

Sampling and analytical methods

Sites were sampled according to SCRP protocols (Sanderman et al., 2011). Sites were sampled to 0.70 m at 0-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.50 and 0.50-0.70 m depth intervals. Bulk density was determined on four cores collected at each site as described by Dane and Topp (2002). Results were calculated as BD in Mg/m^3 (equivalent to g/cm^3) on an oven-dry basis to the nearest 0.01 Mg/m^3. Chemical analyses were conducted on composite samples for each depth increment made from sixteen cores.

Soil samples were prepared for chemical analysis as described by Rayment and Higginson (1992; Method 1B1). All samples were tested for carbonates using HCl and observing the degree of effervescence (Rayment and Lyons, 2011; Method 19D1). No samples required pre-treatment for inorganic C. Total Carbon (TC) and Total Nitrogen (TN) were determined on all samples (to 0.70 m) using a LECO (CNS 2000) combustion furnace (Merry and Spouncer, 1988, Rayment and Higginson, 1992; Method 6B3). Colwell Phosphorus (P) and extractable Sulfur (S) were determined on the surface 0.20 m of soil (Rayment and Higginson, 1992; Method 9B1, Rayment and Lyons, 2011; Method 10D1). Results for TC and TN are reported as g/100g and P (Colwell) and S (KCl_{40}) as ppm.

Results for this paper are also reported as carbon stock in Mg C ha^{-1} calculated by;
Carbon stock (Mg C ha^{-1}) = Carbon concentration (g/100g) x bulk density (g/cm^3) x depth (cm)

Statistical analysis

Statistical analyses were performed using GENSTAT v.8 (VSN International Ltd, UK) software. Differences at $P = 0.05$ between means of C stock (Mg C ha^{-1}) for comparison of sites were assessed using ANOVA. Linear regression was based on 95% confidence intervals.

Results

Soil type and location

Soil type significantly affected the concentration (g/100g) and C stock in soil in the Monaro region. However, there was considerable variation within soil type (Figure 2). The mean mass of C in basalt derived soil was 159 Mg C ha^{-1} (to 0.70 m) which was significantly higher ($P < 0.001$) than deep granite derived soil with 76 Mg C ha^{-1} (to 0.70 m) and shallow granite derived soil ($P < 0.001$) with 43 Mg C ha^{-1}. Deep granite derived soil had a significantly higher ($P < 0.05$) mass of C to 0.70 m compared with shallow granite derived soil. There was also a significant difference ($P < 0.05$) in the mean mass of C in deep granite derived soils in the Monaro and Boorowa regions (Figure 2); 76 *vs* 52 Mg C ha^{-1} to 0.70 m.

Management: pasture type, grazing management and soil fertility

There was no significant difference in the mean mass of C in soil between native and introduced perennial pastures in either region. Therefore sites were grouped by soil type and climate to compare grazing management. There was no significant difference in the mean mass of C with grazing management in the Monaro region. However, in the Boorowa region continuously grazed sites had a significantly ($P < 0.05$) higher mass of C compared with rotationally grazed sites (56 *vs* 49 Mg C ha^{-1} to 0.70 m).

The surface 0.20 m of soil from all sites were compared to investigate the relationship between TC (g/100g) and TN (g/100g), P (ppm) and S (ppm). Based on a linear regression model (95% confidence interval) there were strong correlations between TC (g/100g) and TN ($R^2 = 0.97$; Figure 3), P ($R^2 = 0.64$; Figure 4) and S ($R^2 = 0.70$; Figure 5).

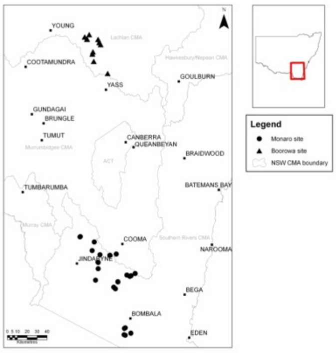

Figure 1. Location of Monaro and Boorowa study sites, south-eastern NSW.

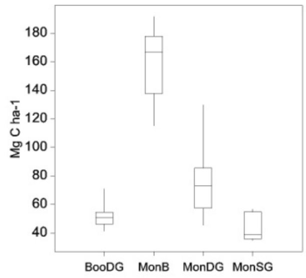

Figure 2. Box plot of the mean mass of C (Mg C ha^{-1}) in soil for sites in the Monaro (basalt; MonB, deep granite; MonDG and shallow granite; MonSG) and Boorowa regions (deep granite; BooDG). The minimum, lower quartile, median, upper quartile and maximum are graphed.

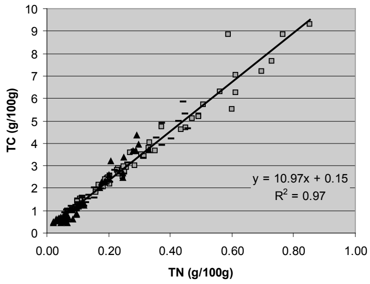

Figure 3. Distribution of total carbon (TC g/100g) and total nitrogen (TN g/100g) in soil under perennial pastures in the Monaro and Boorowa regions. Linear trend line for all samples 0-0.20 m.

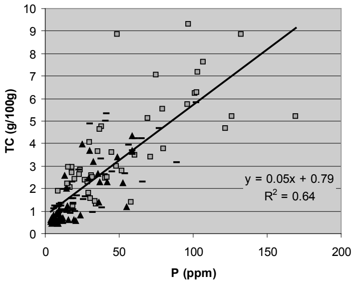

Figure 4. Distribution of total carbon (TC g/100g) and available phosphorus (P ppm) in soil under perennial pastures in the Monaro and Boorowa regions. Linear trend line for all samples 0-0.20 m.

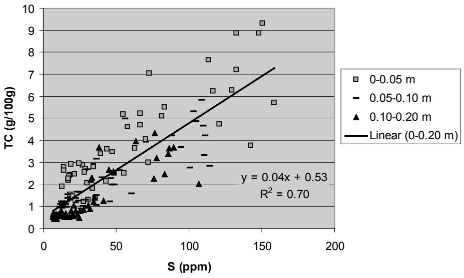

Figure 5. Distribution of total carbon (TC g/100g) and extractable sulfur (S ppm) in soil under perennial pastures in the Monaro and Boorowa regions. Linear trend line for all samples 0-0.20 m.

Discussion and conclusions

Our observations support the conclusion that sequestration of C in soil is influenced by soil type, soil depth and climate. The soils in this study varied in parent material, texture and depth; creating soil with contrasting water and nutrient retention capacity. These factors influenced biomass production, hence supply of OM to the soil, and OM decomposition; explaining the relatively high TC in the clay and nutrient rich basalt derived soil compared with the granite derived soil from both regions (Figure 2). Climate seems to have also influenced C sequestration in the deep granite derived soil; with a significantly larger mass of soil C in the Monaro region compared with the Boorowa region. We propose that this is attributed to colder soil temperatures and more variable rainfall which has limited OM decomposition thus increasing soil C accumulation in the Monaro region.

The type of perennial pasture did not effect C sequestration in this study, which agrees with Chan et al. (2010) study. This may be explained by the preceding 10 years of dry conditions which could lead to underperforming introduced pastures. If this is correct, further research is required to obtain more data on C stock variation with pasture type through years of ‘average’ climate. From a management perspective, the possibility of choosing pasture species to increase C sequestration in soil may be greatly limited by seasonal climatic variations. From a C trading perspective, if there was a difference in C stock with pasture type and this has been reduced due to the drought, then the C sequestered is not persistent and therefore not suitable for a trading scheme with permanency rules.

Grazing management influenced C sequestration in the Boorowa, but not the Monaro region; with continuously grazed pasture having significantly more C in soil compared with rotationally grazed pastures. Annual stocking rate (DSE) did not significantly influence this result and therefore further research is required to determine why these continuously grazed pastures contributed more OM to the soil. Chan et al. (2010) observed no significant difference with grazing management in the surface 0.30 m of soil. Interestingly, if we compare the same soil depth (0-0.30 m) there is no significant difference with grazing management in either region of our study. This highlights the importance of studying C sequestration through the whole soil profile (that is, deeper than 0.30 m) and suggests that grazing management can influence subsoil C sequestration.

The results of this study show that C sequestration is strongly related to soil fertility (Figures 3, 4 and 5). Adequate pasture nutrition increases herbage mass production (Chan et al., 2010, Davies et al., 1998, Garden et al., 2001) and N, P and S are important for biochemically stabilising C in soil, protecting the humified OM from further decomposition (Kirkby et al., 2011). Soil fertility can be influenced by land managers. However, this may come at a substantial cost and it may not be financially viable to make the decision purely for C trading purposes.

This study has shown that soil type (including depth) and climate are the main factors influencing C stock in soil. These are not factors that are practically or cost-effectively influenced by land management. Therefore, it can be argued that soil type and climate will determine which land managers (given the same farming system) are more likely to benefit from soil C trading schemes. Having said that, for a given soil and climate there are practices such as maintaining adequate crop and pasture nutrition that could influence C stock in soil. However, increasing C in soil for credits alone is unlikely to be cost effective in most circumstances.

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