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) parent material (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 parent material (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: organic matter, total carbon, decomposition, climate, pasture, soil fertility

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 (Lal 2004). 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 through 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 (Lal 2004, Six *et al.* 2002). 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 (West and Six 2007).

It has been suggested that well-managed, perennial pastures may maximise C sequestration in agricultural soils (Chan *et al.* 2010, Sanderman *et al.* 2010). Compared to most agricultural crops, perennial pastures produce more below ground inputs with greater soil persistence. This paper examines the variation in C concentration and stock (Mg C ha^{-1}) in soil under perennial pastures in NSW. Comparisons include: i) parent material, 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 pairs; some sites being continuously grazed without rest (CG) and other sites being grazed and then rested for a period of time (RG).

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 (BD) 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). Results for this paper are also reported as carbon stock in Mg C ha^{-1} calculated by multiplying the carbon concentration (g/100g), BD (g/cm^3) and depth (cm). Colwell Phosphorus (P) and extractable Sulfur (S KCl_{40}) 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 mg/kg.

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.

Results

Parent material and location

Parent material significantly affected the concentration (g/100g) and C stock in soil in the Monaro region. However, there was considerable variation within parent material (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 parent material 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 was compared to investigate the relationship between TC (g/100g) and TN (g/100g), P (mg/kg) and S (mg/kg). 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).

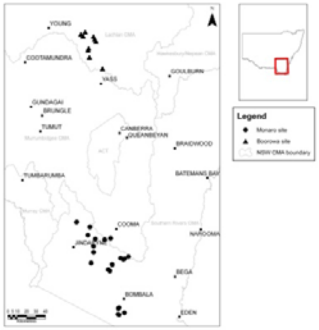

Figure 1. Location of Monaro and Boorowa study sites, south-eastern NSW.

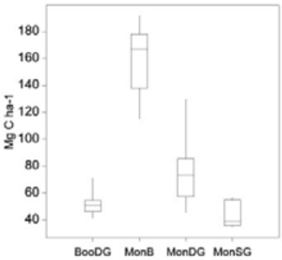

Figure 2. Box plot of the mean mass of C (Mg C ha^{-1}) in soil for sites in the Monaro (basalt; MonB, deep granite; MonDG and shallow granite; MonSG) and Boorowa regions (deep granite; BooDG). The minimum, lower quartile, median, upper quartile and maximum are graphed.

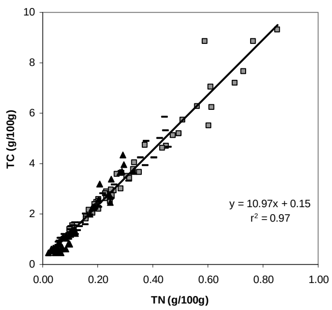

Figure 3. Distribution of TC (g/100g) and TN (g/100g) at all study sites. Different depths are represented: ■ 0-0.05 m, - 0.05-0.10 m and ▲ 0.10-0.20 m. Linear trend line for all samples 0-0.20 m.

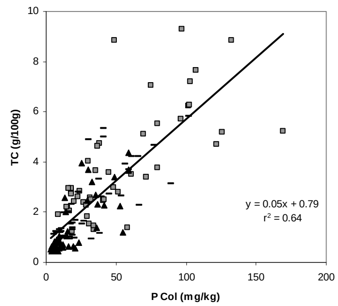

Figure 4. Distribution of TC (g/100g) and P Colwell (mg/kg) at all study sites. Different depths are represented: ■ 0-0.05 m, - 0.05-0.10 m and ▲ 0.10-0.20 m. Linear trend line for all samples 0-0.20 m.

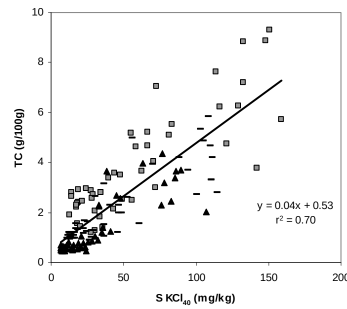

Figure 5. Distribution of TC (g/100g) and S KCl_{40} (mg/kg) at all study sites. Different depths are represented: ■ 0-0.05 m, - 0.05-0.10 m and ▲ 0.10-0.20 m. Linear trend line for all samples 0-0.20 m.

Discussion and conclusions

Our observations indicate that soil C sequestration is influenced by parent material and climate. Inherent soil properties such as structure, clay content and depth influence the supply and accumulation of OM in soil (Rees *et al.* 2005). Basalt derived soil from the Monaro region had higher a concentration of clay in the A horizon compared with granite derived soil (>20 vs. 10-20 %, data not presented) and were typically well-structured throughout the profile compared with the moderately to poorly structured granite derived soil. The basalt derived soil also had inherently higher nutrient concentrations, particularly P, compared with granite derived soil and had a greater water holding capacity. These attributes impact biomass production, hence supply of OM to soil and the rate of OM decomposition with soil high in clay more effective in protecting OM from decomposition than those with a low clay content (Six *et al.* 2002).

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. Decomposition is largely influenced by soil temperature and moisture and correlates positively with these two factors. The mean annual rainfall (1995 to 2010) in the Boorowa region was 555 mm with mean annual maximum and minimum temperatures of 22 and 7°C compared with 514 mm in the Monaro region and 20 and 4°C respectively. The mean annual soil temperature (2005 to 2010) for granite derived soil in the Monaro region was 12°C (ranging from 3 to 23°C) at the soil surface, 15° (5 to 26°C) at 0.10 m and 15°C (5 to 25°C) at 0.20 m. We propose that more variable and lower rainfall and colder soil temperatures in the Monaro region has lead to less OM decomposition increasing soil C accumulation.

The type of perennial pasture did not affect C sequestration in this study. Chan et al. (2010) obtained a similar result. 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 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 CG pasture having significantly more C in soil compared with RG pastures. Annual stocking rate (DSE) did not significantly influence this result and further research is required to determine why these CG 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 there is no significant difference with grazing management. This highlights the importance of studying C sequestration deeper than 0.30 m and suggests that grazing management may influence subsoil C sequestration.

The results of this study show that C sequestration is strongly related to soil fertility (Figures 3, 4 and 5). Soil fertility is inherent, however it can be enhanced by land management. Adequate pasture nutrition increases herbage mass production and N, P and S are important for biochemically stabilising C in soil, protecting the humified OM from further decomposition (Kirkby *et al.* 2011). The range in C stock for parent material indicates that managing soil fertility may enhance soil C sequestration. However, this may come at a substantial cost and may not be financially viable purely for C trading purposes.

This study has shown that parent material and the associated inherent soil properties and climate are the main factors influencing C stock in soil in the Monaro and Boorowa regions. These factors are not 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. That said, for a given parent material and climate there are practices such as maintaining adequate crop and pasture nutrition that could influence C stock in soil.

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