

The effects of management and vegetation on soil carbon stocks in temperate Australian grazing systems

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Abstract. The natural spatial variability in soil organic carbon (SOC) found under perennial pasture systems can make it difficult to determine differences between contrasting agricultural management practices. Pasture composition in large, extensively grazed paddocks can give an indication of pasture growth, utilisation and fertility that influence SOC and are a result of management over the longer-term. This paper examines SOC stocks on the central and southern tablelands of NSW, Australia (average rainfall from 615 to 915 mm and average annual temperature from 10.6 to 15.6°C) at three scales (regional, between similar sites and within site) to determine the influence of management, pasture composition, herbage mass and root mass. After allowing for variability due to climate, landscape and soil properties there were no differences in management comparisons, e.g. high v low fertiliser input, introduced v native pastures and rotational grazing v set stocking. The total herbage mass measured at the time of sampling had a significant relationship with SOC between and within sites and the presence of some species was associated with lower SOC. Root mass measured at an intensively monitored site showed a significant relationship with SOC. These results reflect the complexity of grazing/pasture systems, with natural variability explaining most of the variability in SOC stock; and pasture productivity leading to higher root production explaining differences in SOC levels rather than grazing management.

Keywords: Soil organic carbon, perennial grasses, pasture composition, root biomass, grazing management.

Introduction

Globally, grasslands have potential to sequester 0.11 to 3.04 t C/ha/yr of soil organic carbon (SOC) through improved land management (Conant *et al.* 2001), although sequestration rates >1 t C/ha/yr are rare. In temperate Australia, Chan *et al.* (2011) suggests SOC increases in the range of 0.5-0.7 t C/ha/yr to 30 cm are possible with improved nutrient and grazing management. Conant and Paustian (2002) highlighted the large potential to increase SOC sequestration by ceasing overgrazing. The amount of SOC that can be sequestered is determined by carbon carrying capacity (CCC), which is influenced by climate and edaphic factors (soil type, fertility, topographic position); and current SOC levels. Sequestration rates are higher in early years and decrease gradually over time with net sequestration likely to continue for 40 years (Conant *et al.* 2001) until the SOC saturation level (or CCC) is reached. The multiple benefits of climate change mitigation and improved soil function and productivity from higher SOC (*e.g.* land restoration, soil stability, nutrient cycling) make understanding the effect of different management practices on SOC sequestration mechanisms

of vital importance.

While improved management to increase pasture production has potential to sequester SOC, results vary and unravelling the effect of management from natural variation in SOC is challenging. SOC can also increase, decrease or remain stable as a result of increases in grazing pressure across different soil types, vegetation types and climates, as grazing influences the factors that control SOC in a complex way (Derner *et al.* 2006; Pineiro *et al.* 2010). Grazing management affects SOC through its effect on net primary production (NPP) and pasture composition. Briske *et al.* (2008) found that primary productivity was reduced by grazing that left insufficient leaf area for photosynthesis to maintain or grow new roots (SOC inputs) and increased by regular defoliation at appropriate grazing levels, but no advantage on pasture or animal production between rotational and continuous grazing.

The contribution of roots to SOC is significantly greater than that of above ground biomass. Rasse *et al.* (2005) found that the greater retention of root- than residue-derived C is due to: (1) chemical recalcitrance (*e.g.* high lignin, low nutrients resistant to decomposition); (2)

physico-chemical association with soil minerals (tight chemical bonds and binding agents in soil aggregation); and (3) physical protection (roots bind soil aggregates, roots within micro-aggregates protected from microbes). Grazing and soil fertility influence pasture composition and grazing management can lead to a greater proportion of perennials with higher root:shoot ratios and root mass than annuals/forbs, that would therefore be expected to result in higher SOC levels.

This paper examines SOC stocks at three scales (regional, between similar sites and within site) to determine the influence of management, pasture composition, herbage mass, ground cover and root mass on SOC. It is hypothesised that optimal management (moderate stocking rate, active grazing and optimum fertility management) will improve above and below ground NPP (not directly measured), pasture composition, shoot to root ratios and thus increase SOC.

Methods

A survey of 116 sites across the central and southern tablelands of NSW, Australia (average rainfall from 615 to 915 mm and average annual temperature from 10.6 to 15.6°C) was conducted to determine the influences of climate, soil type, landscape, management over the previous 10 years and pasture composition on SOC stocks. There were 110 sites representing agricultural management *i.e.* high v low superphosphate application on Dermosol (basalt) soils ($n = 49$), introduced v native pasture and set stocking v rotational grazing ($n = 36$) on Chromosol (Silurian granites and dacite) soils, and 25 sites on Chromosols (meta-sediments), with a further 6 ungrazed open grassy woodland sites (3 each on Chromosols and Dermosols). A detailed description of the experimental methods is provided in Badgery *et al.* (2013) and Sanderman *et al.* (2011). Briefly, a 25 x 25 m sampling site was established in each paddock, 10 soil cores were extracted and cut at depths of 0 - 10, 10 - 20 and 20 - 30 cm. SOC was measured on the <2 mm soil fraction for each depth using high temperature oxidative combustion. Bulk density (g/cm^3) was calculated and the SOC stock (t C/ha) determined for each sample. Pasture composition, herbage mass including litter and ground cover were visually

assessed and cut from directly above each of the 10 soil cores sampled per site.

Root mass was examined at an additional site (Chromosol). Soil and roots were collected from 2 soil pits sited for similar pasture composition and heterogeneity (patchiness), slope, position and aspect. Ten samples of equal volumes of soil were collected from each pit at depths to 65 cm, 5 from directly below a perennial grass plant and 5 from the area between plants. Root mass data from a subset of samples taken from 0-5, 20-30, 30-40 and 55-65 cm are used here. Roots were removed, washed to remove soil and oven dried at 60°C for 48 hours. SOC was calculated as for the main study. Further details are provided in King (2013).

Results and Discussion

Regional survey

None of the agricultural management comparisons showed differences in SOC stocks (t C/ha) or concentration (g/100g). However, when the high and low input sites (on Dermosols) were compared to the ungrazed native vegetation sites ($n = 3$), there was lower SOC for the ungrazed sites at 0-10 cm (30.3 ± 0.99 v 21.5 ± 1.44 t C/ha , $P = 0.014$), but there were no differences between the agricultural management and ungrazed sites on the Chromosol soils.

This result illustrates that agricultural management can improve SOC from the inherent levels found in ungrazed native vegetation. Heavy grazing has been reported to increase SOC in previous studies (*e.g.* Reeder *et al.* 2004), but not in all situations (Pineiro *et al.* 2010). In this study, the increase in SOC is likely to be a response from P fertiliser application (Chan *et al.* 2010) over a long period before the management data was collected, but may also be related to increased N availability or root mass under grazing (Pineiro *et al.* 2010). The difference between the agricultural and ungrazed sites was only evident in the Dermosols, which have higher clay content, and not in the Chromosols. The higher clay soils are better able to protect carbon from decomposition and retain higher levels of SOC (Oades 1988).

Using stepwise multiple regression, environmental

Table 1. The environmental and vegetation variables that influenced soil carbon stocks (t C/ha) at 0-10 cm across 110 agricultural management sites. The residuals from the environmental variables were used in the vegetation | environment regressions.

Variables	Adj R ²	Parameter	Estimate	SE	P-value
Environment ($P < 0.001$)	0.49	Constant	124.2	21	<0.001
		Si _{MIR} (mg/g)	-0.117	0.0213	<0.001
		Elevation (m)	0.021	0.004	<0.001
		Fe _{MIR} (mg/g)	-0.207	0.0515	<0.001
		Clay _{MIR} (mg/g)	0.017	0.00698	0.018
		Al _{MIR} (mg/g)	-0.099	0.0488	0.045
		Average rainfall (mm)	-0.017	0.00972	0.08*
Vegetation Environment ($P = 0.004$)	0.15	Constant	-0.398	0.212	0.064
		Herbage mass (kg/ha)	0.176	0.0578	0.003
		<i>Plantago lanceolata</i> (%)	-42.4	16.7	0.013
		<i>Eleusine tristachya</i> (%)	-3.59	1.59	0.026
		<i>Microlaena stipoides</i> (%)	-0.671	0.318	0.037

MIR spectra were used to predict clay (CLAY_{MIR}) and X-ray fluorescence SiO₂ (Si_{MIR}), Al₂O₃ (Al_{MIR}) and Fe₂O₃ (Fe_{MIR}). The overall significance of the model is in parenthesis. *Rainfall has a strong positive relationship with SOC, however, it is a covariate with elevation which accounts for its relative insignificance in this model.

variables (soil properties, climate and landscape) accounted for 49.4% of the variance in SOC stocks at 0-10 cm (Table 1). The residuals from this analysis were regressed against management, which was not significant, and pasture composition (vegetation). The average pasture composition at the sites accounted for 15% the variance in SOC stocks after the environmental variables had been removed. Standing herbage mass had a positive relationship with SOC, while *Plantago lanceolata* L. (lamb's tongue), *Eleusine tristachya* (Lam.) Lam. (crab grass) and *Microlaena stipoides* (Labill) R. Br. (*Microlaena*) all had a negative relationship. Lambs tongue and crab grass are considered weeds and are associated with pastures that have poor production.

Similar sites (Vegetation influence on SOC)

The influence of vegetation on SOC was investigated in more detail at seven of the sites on Chromosol soils. Once the variance between sites had been removed, there was a negative relationship between *Microlaena* and SOC stock at 0-30 cm and at the soil surface (0-10 cm). At the soil surface, there was also a negative relationship between SOC and the nitrophilic weed *Chenopodium pumilio* R.Br. (goose foot) and a positive relationship with standing herbage mass. The standing dry matter indicates higher productivity and lower utilisation, due to surface influences of land management. The negative relationship between SOC and *Microlaena* was as strong at the soil surface as deeper in the soil suggesting that *Microlaena* is likely to be present on patches that have inherently low SOC at depth, which also affects the surface soil potential to store C. Moreover, the negative relationship with the nitrophilic weed indicates, higher available nitrogen that is often associated with soil disturbance indicating the perennial plants present are not growing to their potential.

Within site variability (roots influence on SOC)

There was a strong relationship between root mass and SOC ($R^2 = 0.83$, $P < 0.0001$); with a stronger relationship between perennial plants (Adj $R^2 = 0.98$, $P < 0.0001$) and weaker directly under perennials (Adj $R^2 = 0.71$, $P < 0.05$). Overall, root mass explains 44% of the variation in SOC stock ($P < 0.0005$) using bivariate analysis, increasing to 85% between perennial plants and 59% under them ($P < 0.001$) (King 2013). The stronger relationship of SOC between plants may be due to greater complexity in the soil ecosystem under perennials and spatial changes in pasture composition and patchiness. SOC and root mass declined with depth, with highest levels found at the soil surface (0-5 cm). Although aboveground biomass was not measured, higher root biomass is associated with higher carbon accumulation and this is dependent on higher aboveground biomass (Fornara and Tilman, 2008).

Conclusion

The lack of variability due to management may indicate several things: (1) The variability in SOC in a paddock is present at a scale greater than the 25 x 25 m quadrat sampled (Singh *et al.* 2012) and the error for the

placement of the quadrat was larger than the differences due to land management. This is caused by variation in micro-environment, soil texture and depth, and grazing utilisation across the paddocks sampled. (2) That the change in SOC over the last 10 years has not been large enough to allow differences between contrasting management to be detected. There have been many examples of changes due to soil disturbance in cropping (reviewed by Luo *et al.* 2010), but experiments showing differences due to grazing are not common in Australia and internationally results have varied (Pineiro *et al.* 2010); although degraded pastures with higher levels of bare ground have been shown to have lower SOC (Badgery *et al.* 2013). The influence of vegetation and roots on SOC may indirectly reflect management through changes in pasture composition (Reeder *et al.*, 2004). Also differences in soil type and texture may interact with grazing in different ways (Pringle *et al.* 2011), making it difficult to tease out differences due to grazing management. These results reflect the complexity of grazing/pasture systems with natural variability explaining most of the variability in SOC stock, and pasture productivity more important in explaining differences in SOC levels than grazing management. The results do however show that higher above ground biomass is linked with higher SOC across many sites and detailed monitoring has linked this to higher root production. With little disturbance of soil occurring that could degrade protected SOC in temperate Australian perennial pastures, then productivity and carbon inputs are likely having the greatest influence on SOC levels.

References

- Badgery WB, Simmons AT, Murphy BM, Rawson A, Andersson KO, Millar GD, Lonergan VE (2013) Soil carbon fractions under crop-pasture systems in Central New South Wales, Australia. *Soil Research* - accepted.
- Briske DD, Derner JD, Brown JR, Fuhlendorf SD, Teague WR, Havstad KM, Gillen RL, Ash AJ, Willms WD (2008) Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* **61**, 3-17.
- Chan KY, Conyers MK, Li GD, Helyar KR, Poile G, Oates A, Barchia IM (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: results of three long-term experiments. *Soil Research* **49**, 320-328.
- Chan KY, Oates A, Li GD, Conyers MK, Prangnell RJ, Liu DL, Barchia IM (2010) Soil carbon stocks under different pastures and pasture management in the higher rainfall areas of south-eastern Australia. *Australian Journal of Soil Research* **48**, 7-15.
- Conant RT, Paustian K (2002) Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochemical Cycles* **16**, 90-1-90-9.
- Conant RT, Paustian K, Elliott ET (2001) Grassland management and conversion into grassland: effects on soil carbon. *Ecological Applications* **11**, 343-355.
- Derner JD, Boutton TW, Briske DD (2006) Grazing and ecosystem carbon storage in the North American Great Plains. *Plant and Soil* **280**, 77-90.
- Fornara DA, Tilman D (2008) Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology* **96**, 314-322.

- King H (2013) Grazing and soil carbon, rooting around for an effect. *Proceedings of the 22nd International Grasslands Congress, "Revitalising grasslands to sustain our communities" Sydney, Australia 2013*
- Luo Z, Wang E, Sun OJ (2010) Soil carbon change and its responses to agricultural practices in Australian agroecosystems: A review and synthesis. *Geoderma* **155**, 211-223.
- Oades JM (1988) The retention of organic matter in soils. *Biogeochemistry* **5**, 35-70.
- Pineiro G, Paruelo JM, Oesterheld M, Jobbagy EG (2010) Pathways of grazing effects on soil organic carbon and nitrogen. *Rangeland Ecology and Management* **63**, 109-119.
- Pringle MJ, Allen DE, Dalal RC, Payne JE, Mayer DG, O'Reagain P, Marchant BP (2011) Soil carbon stock in the tropical rangelands of Australia: effects of soil type and grazing pressure, and determination of sampling requirement. *Geoderma* **167/168**, 261-273.
- Rasse DP, Rumpel C, Dignac M-F (2005) Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant and Soil* **269**, 341-356.
- Reeder JD, Schuman GE, Morgan JA, LeCain DR (2004) Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe. *Environmental Management* **33**, 485-495.
- Sanderman J, Baldock J, Hawke B, Macdonald L, Massis-Puccini A, Szarvas S (2011) National Soil Carbon Research Programme: Field and Laboratory Methodologies. CSIRO.
- Singh K, Murphy BW, Marchant BP (2012) Towards cost-effective estimation of soil carbon stocks at the field scale. *Soil Research* **50**, 672-684.