Soil carbon levels in southern NSW

K.O. Andersson[A] and W.B. Badgery[B]

[A]EH Graham Centre for Agricultural Innovation (Industry & Investment NSW and Charles Sturt University), Orange Agricultural Institute, Forest Rd, Orange 2800;
[B]W.B. Badgery, Orange Agricultural Institute, Forest Rd, Orange 2800
karl.andersson@industry.nsw.gov.au

Abstract: *Soil organic carbon (SOC) levels from 7000 sites in southern NSW were found to vary with rainfall, region, parent material, soil texture, land use and phosphorus status. SOC increased with rainfall in areas to the east and, to a lesser degree, to the south. Pasture sites had higher SOC than cropping sites over the whole area, but this was not generally seen within local regions. Thirteen of the 20 regions in the project area had enough sites with land use information to be able to assess the influence of land use on SOC levels. In 5 of these regions the effect of land use was independent of other influences. Three of these regions had higher OC% on cropping soils than pasture soils in the 10–20 cm layer, 1 region had different effects for the length of pasture phase, and only 1 region had higher SOC levels on pasture soils than cropped soils in the 0–10 cm layer. Medium to heavy textured soils generally had higher SOC levels than lighter textured soils in 16 regions. The parent material from which soils were derived had a substantial influence on SOC. Soils derived from granites tended to have lower SOC than those from finer sedimentary or volcanic materials in the 0–10 and/or 10–20 cm layers in 7 of the 14 regions with sufficient samples to allow comparison. Granite derived soils also had lower SOC than soils from finer parent material differences, for the same texture groupings, in 10 regions. The influence of parent material on SOC indicates differing underlying SOC accumulation and storage potential, suggesting that parent material should be included in soil carbon models.*

Introduction

Soil organic matter (SOM) includes the living parts and remains of plants and animals in the soil such as roots, root exudates, leaves, microflora and microfauna (Post & Kwon 2000). Plants are the main primary source of SOM through surface litter and root growth. In various forms, SOM is a source of energy and nutrients for soil organisms, is recycled as nutrients for plants (Krull *et al.* 2004), provides nutrient and moisture holding capacity (Olness & Archer 2005), and improves soil structure and stability (Krull *et al.* 2004).

SOM is comprised of different atoms and molecules including carbon (C). The proportion of C in SOM changes as it is consumed (decomposed) by soil organisms which obtain nutrients, C and some of the energy stored in the molecular bonds (McGill & Cole 1981). It is commonly accepted that, on average,57% of the mass of SOM is C, although this may range from 30% to 70% depending on the types and amounts of different organic material (Krull *et al.* 2004). C content in organic matter can range from 43% of fresh organic matter (Latshaw & Miller 1924), 35% to over 70% of humus fractions (Reintnam *et al.* 2000, Krull *et al.* 2004) and 50–95% of charcoal (Food And Agriculture Organization Of The United Nations 1983). The C in SOM is generally termed soil organic carbon (SOC). Much of the C obtained by the organisms is respired as CO_2 into the soil air spaces and gradually diffuses through the soil into the atmosphere. The proportion of C in stubble retained as SOC may be as low as 5% (Heenan *et al.* 2004).

Current SOC levels reflect previous plant growth and organism breakdown rates. SOC levels tend to be higher where moisture is higher, temperatures are cooler, soils are more fertile, soil disturbance is less, and where soils have more clay and less sand. SOC levels will be greatest where several of these factors combine.

SOC is important because it positively influences many chemical and physical soil attributes. High SOC levels improve soil structure, water holding

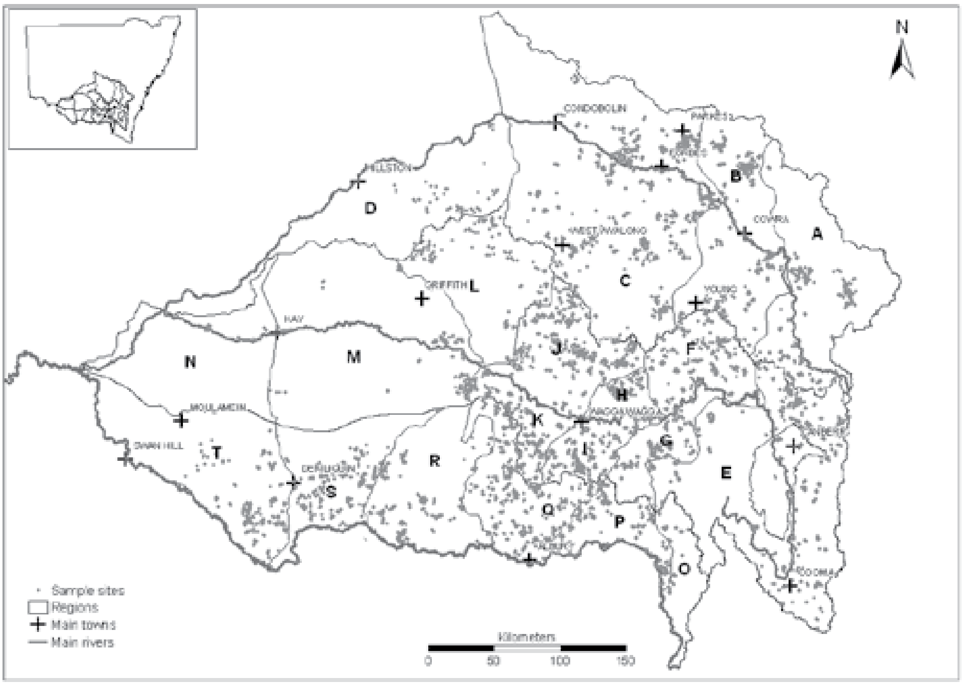

Figure 1. Sample sites, regions and major towns in the project area.

capacity, nutrient availability and enhance microbial activity. SOC has gained much attention recently, as it is viewed as a potential method of sequestering the C in atmospheric carbon dioxide (CO_2) to offset emissions (Dalal & Chan 2001, Post & Kwon 2000). The limitation to using SOC as an offset has been the lack of reliable data on how land use, climate, and soil attributes influence SOC levels and rates of changes. More information is needed about the magnitude of differences to be expected under Australian conditions (Luo *et al.* 2010).

This paper analyses a soil data set of 7000 samples collected as part of the Healthy Soils, Healthy Landscapes and Benchmarking Soils Chemistry (HSHL/BSC) workshop series with landholders in the Lachlan, Murrumbidgee and Murray catchments from 2005 to 2008 (Figure 1). The influence of land use, parent material, rainfall, sample month, phosphorus (P) status and texture on SOC in the 0–10 cm and 10–20 cm layers is examined. This analysis focuses on sites with soils derived directly from parent rocks rather than alluvial deposits.

Methods

Soil samples were collected in conjunction with workshops, which were held throughout the sampled catchments. Landholders were provided with soil corers and GPS units and asked to collect samples (at least 20 cores per bulked sample) from 0–10 cm and 10–20 cm depths from predominantly agricultural paddocks. The GPS location and sample date were recorded. The soil tests variously were part of routine testing, the start of a testing programme, comparison sites or sites of particular interest. Samples were analysed for organic carbon content by Incitec Pivot using the Walkley–Black test (Walkley and Black 1934). Texture (Northcote 1979) was also recorded. The sample fraction >2 mm was removed after grinding with a hammer mill.

Phosphorus (Colwell) and the phosphorus buffering index (PBI) (Burkitt *et al.* 2002) were measured for the 0–10 cm depth. Gourley *et al.* (2007) provided critical Colwell P ranges at different PBI bands for adequate growth of introduced pasture species. The relative P status for these data was classified as VH for P levels

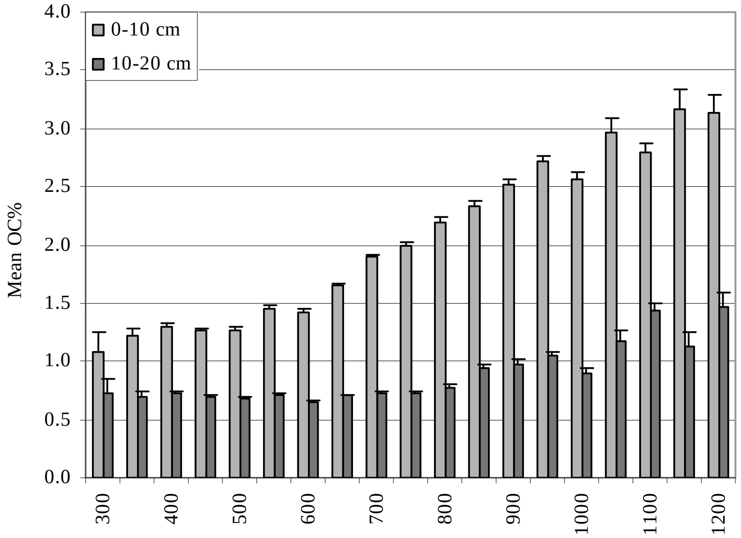

Figure 2. Mean OC% (±se) for the 50 mm rainfall bands at sampled sites.

more than 1.5 times the upper critical value for its PBI, H for P levels above the upper critical value, S for P levels within the critical range, L for P levels less than the lower critical value, or VL for P levels less than 2/3 of the lower critical value.

The data was divided into 20 regions (A-T; see Figure 1) according to topography within the Lachlan, Murrumbidgee and Murray catchments.

Average annual rainfall and soil parent material for each site were assigned using modelled rainfall maps (Hutchinson 2000) and soil landscape maps (DECCW unpublished). The dominant parent material of soil landscapes in the project area were grouped into 23 similar types based on mineral size and inherent fertility. The most common parent materials were granites (1568 sites), metasediments (1094), alluvial (1104) and older alluvial (1090). The remaining parent material groups included various riverine formations and volcanic and sedimentary geologies (each less than 300 sites).

Land use information for 2000 sites was collected via surveys detailing the length of pasture phases, cropping rotations, and fertiliser and soil amendment history. The land use at the time of sampling was summarised into 5 groups: horticulture sites (H), up to 5 years of cropping (C1), more than 5 years of cropping (C2), up to 5 years of pasture (P1) and more than 5 years of pasture (P2).

Statistical analyses of the soil carbon tests were conducted on logit transformed data. Differences in OC% in parent material, land use and texture groupings were tested using the Tukey–Kramer HSD test at the 0.05 level of significance.

Results

Sample month

Time of sampling did not influence SOC.

Rainfall

SOC in both the 0–10 cm layer and the 10–20 cm layer increased with rainfall (Figure 2). The OC% in the 0–10 cm layer increased gradually with rainfall up to 650 mm, above which it increased more rapidly from approximately 1.5% to 3% in the higher rainfall areas. The rate of increase in SOC with average annual rainfall up to 600 mm rainfall was 0.11%/100 mm (ns, r^2=0.75), from 600 to 950 mm it was 0.35%/100 mm (p=0.05, r^2=0.99), and from 950 to 1200 mm 0.17%/100 mm (ns, r^2=0.42). The OC% in the 10–20 cm layer was essentially stable up to 800 mm, above which it increased at 0.15%/100 mm (p=0.05, r^2=0.71).

Rainfall was the main influence on SOC levels in regions D, G, H, I and J. OC% at both depths was higher above an average annual rainfall of 600 mm for regions G, H and I, greater than 500 mm in region J, and greater than 400 mm in region D.

In region D, SOC levels on different parent materials were confounded by rainfall differences. The only independent trend in the region was an increase at both depths above 400 mm annual rainfall.

Regions

Figure 3 shows the average OC% of each region from east to west (left to right) for each catchment. In each catchment the OC% generally decreased from east to west. Southern areas tended to have higher OC% than northern areas but adjacent north-south regions were not generally significantly different.

Within each region the OC% had a wide range. The influence of land use, parent material and soil texture on SOC levels at each depth in each region is summarised in Table 1.

Land use

Land use information provided by landholders indicated that, over the whole project area, SOC levels in the 0–10 cm layer were highest at sites under longer term pasture (P2), were lower under shorter term pastures (P1) and lowest at cropping sites (C1 and C2). In the 10–20 cm layer the P2 sites had higher SOC levels than C1 sites. However, as the pasture sites also had higher rainfall than the cropping sites, it is necessary to look at the SOC levels within a region to observe the influence of land management.

Thirteen of the 20 regions (all regions other than A, D, E, N, O, R and T) had a sufficient number of pasture and cropping paddocks to enable comparison. Six of these 13 regions had a difference in OC% under different land uses, 5 of which were in the 10–20 cm layer. C2 sites had higher OC% in the 10–20 cm layer than P2 sites in regions B and Q, and higher than P1 sites in region M. In region K, the C1 sites had higher mean OC% in the 10–20 cm layer than P2 sites despite lower annual rainfall. Regions F, G and M were the only regions where pasture sites had higher SOC than cropped sites, and after differences in rainfall had been taken into account, this was the case only in regions G and M. P2 sites had higher OC% than C1 sites in the 0–10 cm layer in region G, and higher than C1 and C2 sites in the 10–20 cm layer in region M. Rainfall was not confounding where the

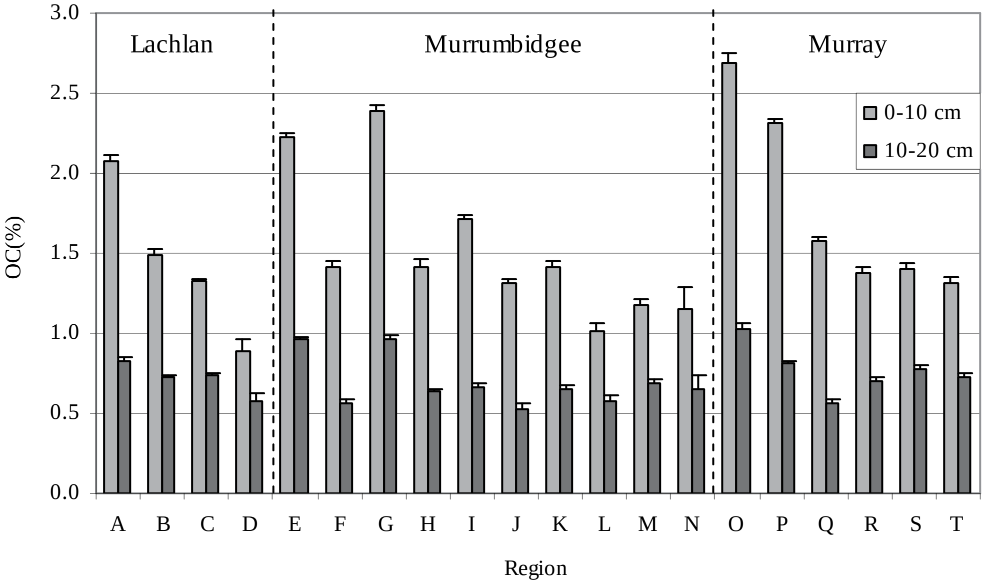

Figure 3. Mean OC% (±se) in the 0–10 and 10–20 cm layers for each region.

Table 1. Summary of the influence of land use, parent material and soil texture on OC% levels in the 0–10 cm and 10–20 cm layers for each region.

Region		Influence					
		Land use		Parent material		Texture	
		0-10	10-20	0-10	10-20	0-10	10-20
Lachlan	**A**	n/a		M>G	M>G	CL>ZL	CL>ZL
	B		C2>P2	VSM>G	VSM>G	LC>SCL	LC>CL>ZL
	C					CL, ZL>MC>SL	ML,LC>ZL
	D	n/a		n/a			
Murrumbidgee	**E**	n/a		M>G^{+}	M>G^{+}		MC>CL>ZL>SCL; LC>ZL>SCL
	F			SVS>G^	SVS>G^	CL>ZL>SL	MC,LC>CL>ZL>SL
	G	P2>C1^{R}					LC,CL>ZL
	H						LC,CL>ZL
	I						
	J			M>G^{Pa}	M>G^{Pb}	CL>MC,ZL	MC,LC,CL>ZL
	K		C1>P2		M>G		LC>CL
	L					LC,CL>ZL	LC,CL>ZL
	M		P2>C2>P1	n/a		LC,CL>SCL	
	N	n/a		n/a		n/a	
Murray	**O**	n/a		n/a		CL>ZL	LC,CL>ZL
	P			M>G	M>G		CL>SCL,ZL
	Q		C2>P2	M>G	M>G		MC,LC,CL>ZL
	R	n/a					
	S			n/a		CL>MC,LC	LC>MC
	T	n/a		n/a		MC,LC,CL>ZL	

Blank cells indicate no effect
n/a indicates insufficient data
For Land use codes, see Methods.
Texture grades: MC = medium clay, LC = light clay, CL = clay loam, SCL = sandy clay loam, ZL = silty loam, SL = sandy loam
Parent material: G = granite, SVS = siliceous volcanics and sediments, M = metasedimentary, VSM= volcanics, sedimentary and metasedimentary
Parent material: unless specified, the data were not confounded by other differences.
+ indicates P2 sites and equivalent rainfall only
^ indicates P2 sites only
P indicates at similar P status
R indicates difference when rainfall not significantly different but no difference when rainfall range is equivalent

cropping sites had higher OC% than the pasture sites. The difference in region G is present where rainfall is not significantly different, but where restricted further to the same rainfall range, P2 and C1 are not different.

In region B, the 10–20 cm layer of the C2 sites had an average OC% of 0.96% compared to 0.65% for the P2 sites. In region K the 10–20 cm layer of the C1 sites had an average OC% of 0.68% compared to 0.41% for the P2 sites. In region, Q the 10–20 cm layer of the C2 sites had an average OC% of 0.75% compared to 0.47% for the P2 sites. In region M, the 10–20 cm layer of the P2 sites had an average OC% of 0.99%, compared to 0.74% for the C2 sites and 0.51% for the P1 sites. In region G, the 0–10 cm layer of the P2 sites had an average OC% of 2.48% compared to 1.31% for the C1 sites.

Texture

The most common texture groups were clay loams and silty loams in the 0–10 cm layer and clay loams, silty loams and light clays in the 10–20 cm layer. In 10 regions texture had a significant effect on OC% in the 0–10 cm layer (regions A, B, C, F, J, L, M, O, S and T). In all except region S, the clay loam and light clay textures consistently had higher OC% levels than the lighter textures (sandy clay loam, silty loam or sandy loam). In regions J and S the heavier MC had lower OC%. These medium clays tended to be more sodic than the other soils.

In the 10–20 cm layer, 14 regions had differences in OC% (regions A, B, C, E, F, G, H, J, K, L, O, P, Q and S). The light clay, clay loam and medium clay textures tended to have higher OC% than silty loam, sandy loam and sandy clay loam textures. Region S again had lower OC% on the heavier soils. Region K was the only one that where clay loams had lower average OC% than other textures.

The range of OC% between texture groups in the eastern regions (regions A, E, O and P) were typically in the order 0.6%–1% and 0.4%–1% in the 0–10 cm and 10–20 cm layers respectively; 0.3%–0.9% and 0.1%–0.9% in the central regions (regions B, C, F, G, H, I, J, K and Q); and 0.3%–0.5% and 0.1%–0.3% in the western regions (regions L, M, S and T).

Parent material

For sites with the same texture classification but derived from different parent materials, SOC levels in soils derived from coarser parent materials (granites and sandstones) had lower OC% levels than finer parent materials (metasedimentary and volcanic geologies) in the 0–10 cm layer in regions A, B, C, F, I, J, P and Q, and in the 10–20 cm layer in regions A, B, F, I, J, K, P and Q. The differences in the 0–10 cm and 10–20 cm layers ranged from 1.05%–1.14% and 0.13%–0.45% respectively in the eastern regions (regions A and P), 0.37%–0.69% and 0.21%–0.46% respectively in the central regions (regions B, C, F, I, J, K and Q).

All parent materials were not present in each region. For example, regions D, M, N, O S and T did not have sufficient sites on different parent materials to compare SOC levels.

Lachlan catchment (Regions A–D)

In region A the sites on metasediments had higher OC% than those on granites at both the 0–10 cm and the 10–20 cm depths (0.5% and 0.25% higher respectively). Land use information was provided for 107 of the 300 sites, the majority being P2, where again metasediments had higher OC% than granites (0.61% and 0.41% higher for the 0–10 cm and 10–20 cm depths respectively). Rainfall was actually higher on the granite sites than the metasedimentary sites. The difference also occurred overall in silty loam textures (0.48% and 0.15% higher in the metasediment derived soils for the 0–10 cm and 10–20 cm depths respectively).

The main sites sampled in region B were from three landscapes: granites, sediments and metasediments, and a mix of volcanics, sediments and metasediments. The latter group had higher OC% than the granites in both the 0–10 cm and the 10–20 cm depths (0.48% and 0.42% respectively). The difference also occurred for the clay loam textures in the 0–10 cm layer (an OC% difference of 0.61%). For the sites with high P status, the granites had the lowest OC% (by 0.4%) of the three groups in the 0–10 cm layer.

Murrumbidgee catchment (Regions E–N)

Region E had a wide rainfall range unevenly distributed over a range of parent materials and land uses. In the higher rainfall areas (> 800 mm), granite and alluvial parent materials were most common and these sites had the highest OC% in the region. Sites on metasediments received less than 750 mm. P2 was the most common land use at sites below 750 mm and, on these, the metasediments had higher OC% than granites in the 0–10 cm and the 10–20 cm layers (by 0.75% and 0.22% respectively).

In region F, samples from P2 sites on a mix of siliceous volcanic and sedimentary parent materials had higher OC% than granite derived soils in both the 0–10 cm and the 10–20 cm layers (by 0.69% and 0.3% respectively).

In region J, lower P soils (P status of S, L and VL) had OC% on metasediments greater than on granites in the 0–10 cm layer (0.42%, 0.45% and 1.1% respectively), and 0.3% lower OC% in the 10–20 cm layer of sites with a P status of L.

In region K, the metasedimentary soils had higher OC% than the granites by 0.2% in the 10–20 cm layer. However, limited information was available to compare, and differences were influenced by land use.

There were no significant differences in SOC levels in regions G, H, I, J and L for land use, parent material or rainfall without different factors confounding relationships.

Murray catchment (Regions O–T)

In region P soils derived from metasediments had higher OC% than those derived from granite at both the 0–10 cm and the 10–20 cm depths (0.31 % and 0.26% respectively). On P2 sites with the same rainfall, the metasediments had 0.55% higher OC% than the granites in the 0–10 cm layer.

In region Q, soils derived from metasediments had higher OC% than the granite-derived soils at both 0–10 cm and 10–20 cm depths (by 0.33% and 0.25% respectively). Limited information was available to compare and differences were influenced by land use.

Comparison with the Cootamundra 1:250 000 map sheet data

The soil landscapes of the Cootamundra 1:250 000 map sheet (Andersson & McNamara, in prep.) lies within the project area and comprises parts of regions B, C, F, H and J. It has laboratory analyses with particle size analyses and OC%. The soils derived from granites in the Cootamundra map sheet had a higher coarse sand content than metasediments (24±3.4%, n=12 cf 14±5.7%, n=5) and a lower mean OC% (1.4±0.3% cf 2.0±0.4). Figure 4 shows the OC% *vs* coarse sand content (CS%) for topsoils. There was no relationship between OC% and clay, silt, fine sand, total sand or gravel content. However, there was a significant relationship ($p=0.001$, adj. $r^2=0.12$) between CS% and OC%. Higher levels of OC% (up to 5.5%) occurred at low levels of coarse sand (below 20%), but these levels declined rapidly as CS% increased. Above 20% coarse sand, OC% was limited to less than 2%.

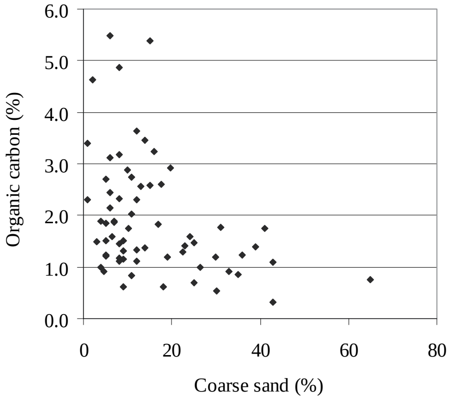

Figure 4. Effect on level of coarse sand on OC% for topsoils in the Cootamundra 1:250 000 map sheet.

Discussion

Rainfall was the primary influence on SOC levels throughout the project area. As average annual rainfall increased, the OC% in the 0–10 cm layer was higher, particularly above 600 mm. However, OC% in the 10–20 cm layer does not increase until above 850 mm. The slower increase in OC% above 1000 mm may be related to cooler temperatures and slower plant growth in high rainfall areas. Chan *et al.* (2010) found no difference in carbon density levels to a depth of 30 cm due to rainfall in 25 paired sites in the 600–800 mm rainfall band between Albury and Gulgong. This paper includes samples taken from a wide rainfall range, which allows a broader look at the effect of rainfall on SOC.

Soil parent material had a consistent influence on OC%. Where sufficient sample sites allowed comparison in a region, soils derived from granite frequently had lower OC% in the 0–10 cm and/or the 10–20 cm layers than soils from finer sedimentary or volcanic parent material, independent of rainfall, land use, texture and P status. The pattern was most pronounced in the more easterly regions (A, B, E, F, P and Q).

Low SOC levels for granitic soils may be explained by a number of factors, including larger soil particle sizes allowing greater air diffusion for the exchange of respired CO_2, lower water holding capacity, lower fertility, poorer structure and less tight bonding of organic compounds to soil particles. These factors can potentially combine, resulting in lower plant growth, faster breakdown of organic matter, and/or less protection of OM from breakdown.

OC% was generally higher under soils with medium textures (clay loams and light clays) in the 0–10 cm layer, and medium to heavy textures (clay loams to medium clays) in the 10–20 cm layer. The heavier textured soils can store more water, protect organic matter from decomposition and be better structured and more fertile, all factors leading to higher SOC levels. Soil texture can, therefore, be a useful guide to potential SOC levels, and coarser parent materials generally tend to give lighter textures, particularly in the surface layers. The HSHL/BSC data also showed that, for soils in a region with the same texture classification, those derived from granites often had lower OC% than those from finer parent materials.

Parent material should be used in soil carbon models. Janik *et al.* (2002) found only limited influence of soil type on carbon dynamics in the Roth-C carbon model. The model uses % clay as a surrogate for soil type, but this does not sufficiently capture the influence of soil particle size. The data from the Cootamundra soil landscapes indicate that coarse sand content could provide a better indication of OC%. A coarse sand content of 20%, above which OC% is limited, may provide a useful guide.

The HSHL/BSC and Cootamundra soil landscapes data indicate that parent material has a pronounced and consistent influence on SOC. Implications of this are:

soils derived from different parent materials in an area can be expected to have different SOC, a difference that was observed to be greater than land use differences;

the potential to increase SOC levels will have different limits for soils on different parent materials; and

soil parent material should be incorporated into carbon modelling to provide greater reliability to predictions of SOC dynamics.

OC% was higher at all sites in the 0–10 cm layer than the 10–20 cm layer, and this difference was greater in the eastern higher rainfall regions than in the lower rainfall areas. This indicates that the majority of the extra OC stored in the upper 20 cm of soils in the eastern regions is close to the surface. Soils in the east are characterised by pale, light textured subsurface layers with low OM content (A2 horizons). The long period of pedogenic formation of these layers indicates that breakdown rates meet deposition rates, and storing more carbon in these subsurface layers is likely to be slow at best. The higher OC% levels observed in the 10–20 cm layer of heavier textured soils indicate that OC stored deeper in the clayey subsoils (B2 horizons) could potentially be retained longer than in lighter surface and subsurface soils.

It is generally expected that soils under pasture will have a higher OC% than under crop (Luo *et al.* 2010, Dalal and Chan 2001, Chan *et al.* 1992). The results here show that the influence of land use on OC% is inconsistent, with only 2 regions (G and M) having higher SOC under pastures than under crop. In region G, this difference is very marginal: where rainfall was not significantly different, a difference in OC% under pasture and crop was found, but when restricted to the same rainfall range, OC% was not different. Two regions (K and L) had higher average rainfall on pasture sites (P2 and P1 respectively) than cropping sites,but still did not have higher OC%. Similarly, Luo *et al.* (2010) found no consistent trend of increase in SOC under conservation agricultural practices.

The land use information did not specify the grazing management strategies or the extent of groundcover. A sample from a looser cropped surface could contain less of the lower OC% subsurface material than a sample from the same depth of a compacted pasture paddock, though the timing of the sample collection would have minimised this error in most cases. Resolution of these issues may explain differences, or lack thereof, in OC% between different land uses. Land management options do have the potential to affect SOC levels (Chan *et al.* 1992), but the results indicate that factors other than land use may be more important in influencing SOC.

Acknowledgements

The author would like to thank Ian McGowen (I&I NSW) for processing rainfall data, Remy Van de Ven (I&I NSW) for assistance with statistical analyses, Mark Young (DECCW) for provision of soil landscape linework, and Dr David Mitchell and Dr Aaron Simmons (I&I NSW) for helpful comments. This work would not have been possible without the participation of the landholders in the Healthy Soils, Healthy Landscapes and Benchmarking Soil Chemistry projects. The HSHL and BSC workshops were conducted by Karl Andersson, Susan Orgill, Colin McMaster, Jennifer Hardwick, David Waters and Sean Roberts from DPI (now I&I NSW). The project was funded by the Murrumbidgee,

Lachlan and Murray CMAs, Environment ACT and the National Heritage Trust.

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