Soil carbon variability of a grassy woodland ecosystem in south-eastern Australia: Implications for sampling

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Abstract

A detailed examination was conducted on two paired-sites (grassy woodland and pasture) in central NSW, Australia, to assess the efficacy of different soil sampling regimes in the context of general ecosystem carbon (C) balance. Specifically, soil organic carbon (SOC) and bulk density (BD) were measured in order to calculate carbon density (CD), used for C accounting purposes. To achieve the same levels of accuracy in estimating the mean for SOC, substantially more samples were required in the highly variable woodland surface soils, whereas sub-surface numbers were more comparable between woodland versus pasture. Woodland soil BD was generally more variable than pasture, this being reflected in the need for larger sample numbers. The SOC variability was in part related to arbitrary demarcation between the soil component and other input sources of C such as the litter and CWD layers. This emphasized the importance of delineation between C pools in an effort to reduce measurement errors. This paper examines some of the issues related to these C pools and the problems of obtaining accurate C estimations.

Key words

Biomass, soil organic carbon; bulk density; spatial variability; paired-site.

Introduction

In recent years, increased attention has been given to the assessment of soil carbon stocks in relation to national scale carbon emissions accounting (e.g. AGO 2005) and for soil condition monitoring (McKenzie *et al.* 2002). In their assessment, McKenzie and Dixon (2006) highlighted the current lack of appropriate soils information and the need to address this problem by obtaining improved data for modelling.

Furthermore, appropriate delineation of the carbon pools (in both biomass and soil) is essential for accurate carbon accounting, as variability of each component is dependent upon this categorisation. Incorporation of surface dead biomass (e.g. litter and CWD) into the soil carbon component is logical as they provide the carbon inputs (Baldock and Nelson 1998). However there are few data available on these, and most soil carbon accounts deal only with that carbon found within the mineral soil (i.e. obtained via laboratory analysis).

The objectives of this study were to examine SOC variability by spatially sampling within the framework of current protocols (McKenzie *et al.* 2000) and to assess the efficacy of given approaches. Focus was placed on two paired-sites consisting of a grassy woodland and adjacent pasture in central NSW, Australia.

Materials and methods

The two paired-sites (1 and 2) in central NSW, consisted of grassy woodlands that were directly adjacent to cleared land now under pasture. Site 1 was located near Orange (S33^{0}21.439'/ E148^{0}54.624', Red Chromosol, 910 m a.s.l. with rainfall of 900 mm/year). The dominant vegetation was *Eucalyptus macrorhyncha, E. bridgesenia*, and *E. melliodora*. An adjacent pasture site was cleared of vegetation in the early 1960s, cropped for a few seasons, before being used for lightly grazed pasture until the present. Site 2 was at Canowindra (S330^{0}32.998'/ E1480^{0}40.343', Red Chromosol, 340 m a.s.l. with rainfall of 677 mm/year). Here the dominant vegetation was *E. Albens* and *Callitris glaucophylla,* with an adjacent cleared site dominated by the grass *Themeda triandra*. The grassy woodlands of both sites have experienced minimal disturbance from fire and stock grazing for many decades and both sites demonstrated highly diverse ground flora.

The soil sampling protocols of the Australian Greenhouse Office (McKenzie *et al.* 2000) recommend a paired-site approach using 25 × 25 m quadrats in both sites, from which a minimum of four samples are extracted. This framework was followed using at least 5 randomly located sampling points (15 and 5 for sites 1 and 2, respectively). In determining soil BD, an excavation method using the measurement technique to determine the volume of the excavated hole (0.20 × 0.20 × 0.05 m depth) was used (adapted from Blake and Hartge, 1986). Incremental sample depths of 0.05 m were taken to a total depth of 0.40 m. Coarse fragments (stones, roots and charcoal >2mm) were separated from all of these BD samples, dried at 40^{0}C and weighed. SOC analysis was predicted using a pre-calibrated mid-infra red spectrometer. Sample numbers (*n*) were calculated using $n = t^2 \times s^2 / d^2$, where, t = Student's t at 95%, s^2 = variance and d = specified acceptable error.

Soil carbon density (CD) was calculated using the equivalent mass approach (Murphy *et al.* 2003). Litter amounts were estimated using 25 × 0.25 m^2 quadrats systematically placed within each of the the main 25 × 25 m sampling areas. All coarse woody debris (CWD) >2.5 cm in diameter, was directly measured within the woodland quadrats. Above and below ground tree and shrub biomass were assessed using the guidelines of Snowdon *et al.* (2002). Below ground tree and pasture root biomass amounts were estimated using a root: shoot ratio of 0.35 and 1.58, respectively (IPCC 2003, Table 3A.1.8, P. 3.168).

Results and Discussion

The C estimates contained within the ecosystem component parts of the two paired-sites 1 and 2 were estimated and summarized in Table 1.

Table 1. Summary of ecosystem carbon (t/ha) of Site 1 (nr. Orange) and Site 2 (Canowindra), central NSW, Australia.

	Trees	Shrubs	Wood site grasses & pasture grass	CWD	All litter classes	Charcoal pieces >2 mm (0-30 cm)	SOC i.e. CD (0-30 cm)	Sub-total ecosystem C	Total ecosystem C
Site 1: wood									
Above ground	106.418	0.045	1.195	9.979	22.796	-	-	140.433	237.8
Below ground	22.792	0.014	0.121	-	-	3.76	73.87	97.557	
Site 1: pasture									
Above ground	-	-	1.213	-	-	-	-	1.213	51.9
Below ground	-	-	1.324	-	-	3.884	45.49	50.698	
Site 2: wood									
Above ground	74.319	0.033	0.906	1.573	24.14	-	-	100.971	176.4
Below ground	24.731	0.01	0.064	-	-	4.357	46.27	75.432	
Site 2: pasture									
Above ground	-	-	2.915	-	-	-	-	2.915	39.8
Below ground	-	-	3.183	-	-	1.209	32.45	36.842	

Some generalisations were possible from Table 1:

- Total ecosystem C amount found in the *E. Macrorhyncha mid-high open-forest* (Hnatiuk *et al.* 2006) was 237.8 t/ha. There had been a total loss of 185.9 t/ha (78.2%) after this ecosystem was converted to pasture (~45 years). This figure also represented an approximation of the C sequestration potential if reafforestation to the same original baseline vegetation was to take place.
- When similar estimates were made for Site 2, the *E. albens sparse mid-high woodland* (Hnatiuk *et al.* 2006) had a total C content of 176.4 t/ha, with a post-clearance C loss of 136.6 t/ha (77.4%) on conversion to pasture.
- Above ground C therefore accounted for 59.0% and 57.2% of the total ecosystem C for Sites 1 and 2, respectively. Corresponding below ground C pools therefore accounted for 41.0% and 42.8%, respectively, of the total.
- A large proportion of the total ecosystem C occurred in the tree biomass of the uncleared sites (44.7% and 42.1% for Sites 1 and 2, respectively). About 75% of the above ground total C was accounted for by the above ground tree C, for both woodlands of Sites 1 and 2. Since this component represents proportionally large C pools, even relatively small differences between C estimate methodologies (e.g. through choice of allometric equation to determine biomass) can be potentially substantial, especially when extrapolated.
- 31.0% and 26.2% of the total woodland ecosystem C was in the 0-30 cm soil depth for Sites 1 and 2. A larger proportion of the pasture ecosystem C was in the same depth of soil, that is, 87.6% and 81.6%, respectively.
- A larger proportion of SOC (0-30 cm) was lost in Site 2 than in Site 1 due to land clearance (38.4% and 29.9%, respectively), probably due to the higher annual mean temperatures at Site 2.
- The mean litter amount for Site 1, when twigs (<2.5 cm diameter) were included, was 22.8 ± 4.21 t/ha (where n = 25). However when ten separate groups, each with only 3 replicate samples were assessed, as recommended in the given protocols (McKenzie *et al.* 2000), the mean litter estimates had a range from

16.8 ± 7.07 t/ha to 32.0 ± 26.7 t/ha. Similar high variability was obtained for Site 2. The large range and wide variability of the 3 replicate samples sets was a reflection of that variability associated with twig inclusion and the problems of determining where the demarcation between components should be, in this case between twigs and CWD. A number of CWD definitions based on a range of CWD diameters, have been reported (Woldendorp and Kennan 2005) making comparisons difficult.

- CWD only accounted for 4.2% and 0.9% of the total ecosystem C for the woodlands at Sites 1 and 2, whereas litter accounted for 9.6% and 13.7%, respectively. CWD estimates using the method described by McKenzie *et al.* (2000) compared with actual total measured amounts (Table 1), underestimated CWD by about 40% and 3% for Sites 1 and 2, respectively. Such uncertainty in CWD estimates, related to high variability of CWD, was also demonstrated by Woldendorp and Kennan (2005).
- Charcoal pieces (>2 mm) in the 0-30 cm soil depth accounted for 1.6%, 7.5%, 2.5% and 3.0% of the total ecosystem C for the Site 1 wood, Site 1 pasture, Site 2 wood and Site 2 pasture, respectively. Whilst charcoal can often constitute between 15 to 20% of the total SOC in the top 20 cm of soil, values can also vary between 0 to 70% for the same depth (Skjemstad and Baldock 2006).

Differences in SOC between the contrasting land uses were apparent only in the surface 0.30 m (Figure 1). For the depth increments close to the surface, SOC amounts in the wood site were approximately double those in the pasture. With subsequent depth increments, amounts became more comparable until a depth of about 0.30-0.35 m after which no significant differences between wood and pasture occurred. This indicates the depth of disturbance through land use change and subsequent management and reinforces the IPCC (1997) recommendation of 0.30 m as a sampling depth for C accounting purposes.

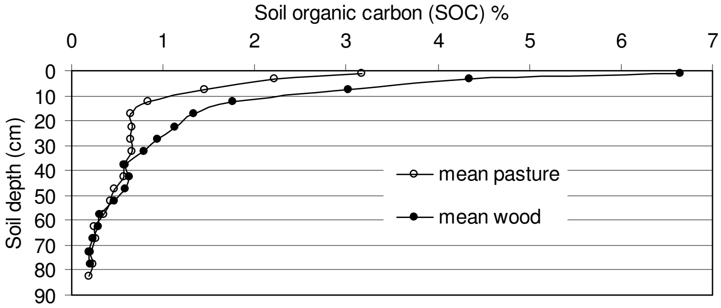

Figure 1. Change in SOC with soil depth for wood and pasture at Site 1.

An assessment of sample number requirements (*n*) for SOC and BD (Figure 2) was made for each soil depth increment. Only the Site 1 results are shown: the wood and pasture of Site 2 showed similar trends. Figure 2 is now discussed in relation to variability.

There is a gradual, but substantial, decrease in SOC *n* requirement from surface to subsurface in the woodland (Figure 2a). In addition, considerably more samples were needed in the surface soil of the woodland, compared to the pasture, at the same error levels. However, for both sites below 0.15 m, SOC *n* requirements were similar for the same levels of error (*d*) which corresponded to those similar amounts of SOC with depth shown in Figure 1. Whilst fewer SOC samples were needed from the surface horizons of the pasture soil, there was a larger *n* for the pasture at 0.25-0.30 and 0.30-0.35 m (CV% of 31.2 and 25.5 respectively, compared with 13.5 and 14.4 for woodland, respectively). This was likely due to the influence of localised concentrations of charcoal found in the pasture, probably due to the method of land clearance i.e. in situ burning of tree stumps/woodpiles. This charcoal inclusion also increased BD variability at these depths (Figure 2d). At the 0.35-0.40 m depth increment is the lowest *n* requirement for both the wood and pasture sites. This probably reflects a general limit of influence from management practices in the disturbed pasture and reduced bioturbation in the undisturbed woodland site as also indicated in Figure 1.

More BD samples would be needed in the woodland than in the pasture to give the same levels of accuracy, as indicated by the *d* values (Figures 2c & 2d). In the woodland soil, fewer BD samples would be required for surface horizons compared to subsurface horizons, with a wider spread of *n* requirements with depth. This was reflected in the corresponding CV% values showing a general increase with depth from 8.8 (0.05-0.10 m) to 15.9 (0.35-0.40 m). This was probably due to an interactive effect of coarse fragments and bioturbation. For the pasture, BD sample number requirements were less variable with depth (Figure 2d), reflected in a narrow CV% range of 4.0-6.7 for all depth increments. This uniformity was probably related to soil slumping due to disturbance, stock compaction, with less bioturbation than occurs in the woodland site.

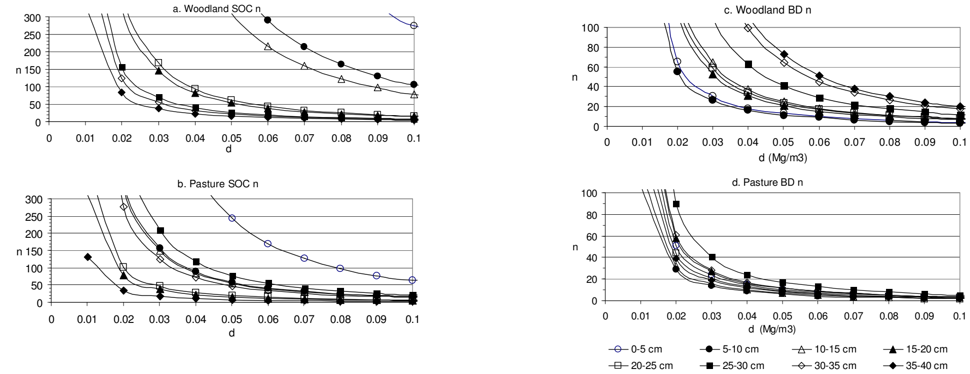

Figure 2. SOC and BD (excavation method) sample number requirements (*n*) in relation to specified acceptable error (*d*) for the woodland and pasture sites at the 95% probability level. Site 1 results presented only: Site 2 showed similar trends.

Conclusion

In estimating SOC amounts, in particular for soil monitoring purposes, sampling intensity has to be sensitive enough to detect long-term change in soil properties. This is dependent upon soil variability, influenced to a large extent by management type and history. While differences in sampling requirements do occur to depth in the soil, it is recommended that at least a minimum of 10 samples be obtained per sampling unit (usually 25 m × 25 m), especially in wooded situations where soil variability is greatest.

This paper has identified a number of errors that may confound accurate quantification of C amounts (both biomass and soil carbon density) for a site. These include natural variations and as well as sampling, measurement and calculation errors. Each one of these sources of variability, if not handled correctly, has the potential to undermine C accounting efforts especially when extrapolated to regional or national scale.

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