Spatial and temporal variability in organic carbon observed in soil under lucerne pastures

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Abstract

Two field trials established in 2005 were sampled during 2008-09 to observe temporal and spatial variability in soil organic carbon levels under mature lucerne (*Medicago sativa*) stands. The study was conducted at Binalong and Gerogery in the high-rainfall cropping zone of southern New South Wales, Australia. Four replicate plots were selected at each location and sampled monthly between February 2008 – January 2009 by taking 10 soil cores at 0-0.1m depth and analysing the samples using the Walkley–Black and Heanes methodologies. Plot area was no more than 10 m^2, and the 4 plots sampled at each location were no more than 20 m apart. Temporal variation in organic carbon levels during the 12 month sampling period was 24-76% (mean 37%) and spatial variation was observed to be 13-46% (mean 30%) using the standard Walkley–Black test with samples sieved to <2 mm. Analysing samples using the Heanes method reduced the mean temporal variability from 37% to 29% and mean spatial variability from 30% to 28%. A subset of samples were ground to a fine powder to increase the homogeneity of the sample before being reanalysed, but temporal and spatial variation in organic carbon values were still shown to be 29% and 24%, respectively. This study demonstrates the magnitude of sampling variability likely to be encountered when quantifying soil organic carbon for possible inclusion in future carbon-emissions trading schemes. Aspects requiring further research are discussed.

Introduction

Farmers and scientists have long been aware of the importance of soil organic carbon (SOC) to soil health and sustainable agriculture. Recently there has also been an increasing interest in the possible role of SOC as a carbon sink for the mitigation of climate change and therefore the possibility of its inclusion in emission trading schemes (ETS). It has been estimated that SOC sequestration has the potential to mitigate 5-14% of global annual greenhouse gas emissions during the next century (Chan et al. 2009). However, for the credible inclusion of soil carbon in trading schemes it is essential to establish robust methodologies by which SOC can be measured and monitored over time.

An accounting system for an ETS must ultimately be based on one or more laboratory methodologies for physically measuring carbon or carbon fractions in soil. The most common test for soil organic carbon in Australian laboratories is the Walkley–Black method (Walkley and Black 1934), but it only measures readily oxidisable/decomposable carbon rather than total SOC (Chan et al. 2010). The Heanes modification (Heanes 1984) of the original Walkley–Black method measures up to 100% of total SOC, including a proportion of the charcoal in the sample. Estimates of SOC using either of these tests will detect labile organic residues including fresh or partly decomposed organic matter (roots, leaves, manure etc), only a proportion of which is ultimately incorporated as SOC (Chan et al. 2010). The current study aimed to monitor the spatial and temporal variability of SOC using conventional sampling and laboratory methodologies to assess how SOC could be accurately assessed in the context of an ETS.

Methods

Site descriptions

Two field experiments were established in 2005, approximately 250 km apart, near Gerogery (35?54'S, 146?56'E) and Binalong (34?34'S, 148?42'E), southern New South Wales, Australia, primarily to examine the performance of lucerne (*Medicago sativa*) cultivars and rhizobia species (R. C. Hayes unpublished data). On completion of the experiments, the sites were retained for a further 12 months for sampling of

SOC. Soil at Gerogery was a Yellow Chromosol and at Binalong was a Yellow Kandosol (Isbell 1996) and at both sites was highly acidic, with $pH_{CaCl2} \leq 4.1$ and Al comprising ≥ 12% of the effective cation exchange capacity in the surface 0.2 m. The Binalong experiment was sown on 5 September 2005, having 40 lucerne cultivar treatments sown as monocultures in plots that were 1 ? 5 m replicated three times. External dimensions of the full experiment (including internal buffers between plots) was 32.5 ? 30 m. The Gerogery experiment was sown on 8 September 2005. The experiment contained one lucerne cultivar, Sardi 10, inoculated with 4 rhizobia treatments sown to plots with either nil or 5 t/ha limestone. Plots were 5 ? 2 m and treatments were randomised and replicated four times with external dimensions of the experiment being 23 ? 23 m.

Sampling and laboratory analysis

Four unlimed plots at Gerogery sown to lucerne cv. Sardi 10 inoculated with the commercial rhizobia (RRI 128; plots 3, 12, 18 and 27) and three plots at Binalong with the same treatment (plots 29, 71 and 88) were selected for sampling to monitor variability in soil carbon. One additional plot was selected at Binalong (plot 24) to provide a fourth 'replicate' as at Gerogery. This plot was simply sown to a different cultivar of lucerne, but was shown in the previous study to have similar plant density and productivity as the other three selected plots at this site (R. C. Hayes unpublished data). The maximum distance between the 4 'focus' plots at both sites was 20 m. One soil sample was collected from the 0-0.1 m depth from each focus plot monthly for 12 consecutive months between February 2008 and January 2009. Each soil sample contained 10 cores extracted from between lucerne plants using a hand-held corer, 0.02 m in diameter. Care was taken to clear away herbage residues from the surface prior to inserting the corer into the soil, and the core never included a lucerne tap root. On each occasion soil was collected, the lucerne herbage in each of the focus plots was cut at ~ 0.02 m above the soil surface and the herbage removed. Soil was dried at 40?C for ~ 72 hours before being homogenised through a 2 mm sieve. All material other than gravel (> 2 mm) was included in the samples. Each sample from both sites was sub-sampled and analysed for SOC using both the Walkley–Black (Walkley & Black 1934) and Heanes (Heanes 1984) methods. Results from Plot 24 at Binalong in December were erroneously low and have been excluded from the analysis (Fig. 1). A further sub-sample was taken from each of the samples from Gerogery and ground to a fine powder using a ring and puck mill (100% passing through a 0.15mm sieve) to further improve homogeneity. These finely ground samples were also analysed for SOC using the same two methodologies. The coefficient of variation (c.v.) was calculated for spatial and temporal differences (Fig. 1) by dividing the standard deviation by the mean and expressing as a percentage.

Results

Soil organic carbon varied in time (Table 1, Figure 1) and space (Figure 1) regardless of the analytical method. Across both sites, the Heanes method increased the SOC value by 6.6% compared with the Walkley–Black method. Using the Heanes technique increased plot averaged SOC at each of the sites by as much as 28% (at Gerogery in February). However, on 5 occasions the Heanes method actually gave a slightly reduced value for SOC, by as much as 3.3% (at Binalong in December, Table 1).

Table 1. Average soil organic carbon (%; mean of 4 plots) measured at Binalong and Gerogery over 12 consecutive months and analysed using both the Walkley-Black and Heanes techniques.

Month	**Binalong**			**Gerogery**		
	Walkley-Black	Heanes	% Method difference	Walkley-Black	Heanes	% Method difference
February	1.47	1.73	17.7	1.21	1.55	28.1

March	1.54	1.73	12.3	1.30	1.53	17.7
April	1.48	1.64	10.8	1.38	1.41	2.2
May	1.53	1.64	7.2	1.43	1.44	0.7
June	1.56	1.69	8.3	1.30	1.42	9.2
July	1.43	1.54	7.7	1.28	1.41	10.2
August	1.53	1.57	2.6	1.28	1.34	4.7
September	1.59	1.63	2.5	1.35	1.34	-0.7
October	1.54	1.58	2.6	1.55	1.54	-0.6
November	1.65	1.62	-1.8	1.41	1.48	5.0
December	1.53	1.48	-3.3	1.45	1.57	8.3
January	1.68	1.78	6.0	1.70	1.68	-1.2
% Maximum difference	*17.5*	*20.3*		*40.5*	*25.4*	
Average	*1.54*	*1.64*		*1.39*	*1.48*	

Soil organic carbon at Binalong varied between 1.25% (plot 88, October) and 1.94 % (plot 24, November) using the Walkley–Black method (Fig. 1a). Soil organic carbon at Binalong was marginally higher with the Heanes method, ranging from 1.35% (plots 88 and 71, July) to 2.22% (plot 24, January; Fig. 1b). At Gerogery, SOC ranged from 1.06% (plot 18, February) to 2.01% (plot 27, January) using the Walkley–Black method, in contrast to the Heanes method where the range was 1.14% (Plot 18, September) to 1.81% (plot 27, January; Fig. 1c & d). Where the samples were ground to a fine powder, SOC at Gerogery ranged from 1.22% (Plot 18, May) to 1.96 (plot 12, October) using the Walkley–Black method and from 1.32% (Plot 18, September) to 2.16% (plot 12, December) using the Heanes method (Fig. 1 e & f).

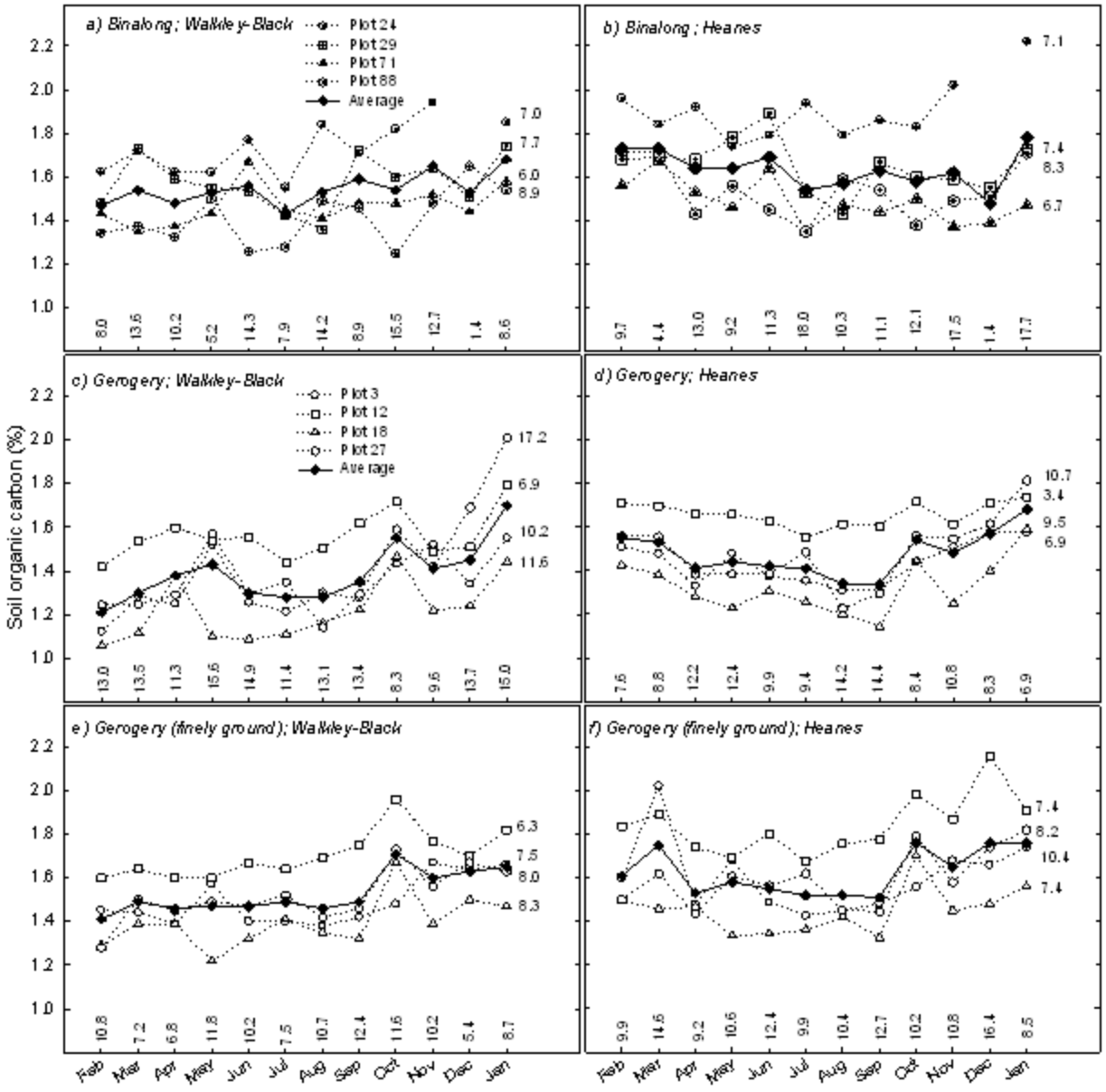

Figure 1. Soil organic carbon (%) measured at the 0-0.1 m depth on 4 plots over 12 consecutive months at Binalong (a & b) and Gerogery (c, d, e & f), analysed using the Walkley–Black (a, c & e) and Heanes (b, d & f) methods after samples were passed through a 2 mm sieve (a, b, c & d) or a 0.15 mm sieve (e & f). The coefficient of variation is given on each graph for spatial variability between plots on a given date (*x*-axis) and temporal variability of individual plots over time (*y*-axis).

Averaged across both sites, spatial variability in SOC (difference between highest and lowest SOC values at any given sampling date, expressed as %) ranged from 13-46% with a mean of 29.7% using the Walkley–Black method. This variability was reduced slightly to 28.3% using the Heanes method even though the range was slightly wider (10-51%). All the extremes in spatial variability were observed at the

Binalong site. Spatial variability of SOC of the finely ground samples from Gerogery was 24% using the Walkley–Black method (range 13-33%) and 29% (range 21-46%) using the Heanes method (Fig. 1).

Temporal variability (difference between highest and lowest SOC values observed in the one plot over 12 months, expressed as %) was highest (76%) in plot 27 at Gerogery where SOC ranged between 1.14% in August to 2.01% in January using the Walkley–Black method. Across both sites, temporal variability in SOC ranged from 24-76% with a mean of 36% using the Walkley–Black method. The Heanes method reduced this variability to a mean of 29% (range 12-48%). With one exception, all the extremes in temporal variability were observed at the Gerogery site (Fig. 1). Temporal variability in SOC of the finely ground samples from Gerogery was also 29% (range 21-37%) using the Walkley–Black method, increasing slightly with the Heanes method to 32% (range 27-42%).

Discussion and Conclusion

This study has identified substantial levels of both spatial and temporal variability in SOC using standard methods for soil sampling and analysis. The high level of spatial variability was observed on very small plots each no greater than $10m^2$ and no further than 20m apart. It is highly likely that the magnitude of variability observed at the paddock scale would be even greater than that observed in the current study. The sampling regime in our study was the equivalent of 1-2 soil cores/m^2 which is far more intensive than can be expected at the paddock scale. Also, there are additional sources of error at the paddock scale due to aspect, topography, grazing management, soil type, fertility and botanical composition which may all impact upon levels of SOC. Our estimations of variability are therefore probably an underestimation of the variability that could be expected at the paddock or farm scale under an ETS.

The consistency of spatial and temporal variation between the Walkley Black and Heanes methods implies, predictably, that the variability in SOC occurs in the labile fraction. The consistency of the spatial and temporal variation between the 2 mm sieved and the finely ground samples implies that the variation in SOC comes from field sources more than from sub-sampling and analytical sources, despite the highly intensive sampling regime and the apparent consistency between plots. Hence the dynamic cycling of fresh residues in pastures is likely to provide ongoing sampling problems for the determination of SOC. It is increasingly common for people, including scientists (such as Miklos et al. 2010), to speak about the possibility of including SOC in an emissions trading scheme to redress the increasing levels of atmospheric carbon. However, it is our view that any such move be made cautiously and, within the context of the carbon accounting requirements associated with an ETS, account is taken of the relatively large variability in the measurement of SOC. Even with high spatial precision (Miklos et al. 2010), temporal variation will remain problematic.

There are a number of aspects that require further research. The current study examined changes in SOC at only two locations over one 12-month period. It is likely that variability in SOC will be affected by soil type, and will also be related to particular seasonal conditions (eg drought, waterlogging *etc*) as this directly impacts upon plant growth. Defoliation regime is also of importance as, for example, return of carbon through livestock faeces and trampled herbage would almost certainly have a contrasting effect on SOC relative to forage conservation. The analysis of particulate OC needs to be undertaken to quantify transient pools of C in the soil, although preliminary analysis suggests that particulate OC does not explain all the variability. Soil depth is another important factor not reported within the current paper. Some species, such as lucerne, have a greater proportion of deeper roots than annual pasture species, and these deeper roots are likely to have an effect on deep SOC which would also need to be accounted for.

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