# Spatial variability of soil carbon at the paddock scale

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**Abstract**
This work reports on a dynamic sampling and monitoring strategy to measure soil carbon at the paddock scale. The current method used in Australia for estimating soil carbon is given in McKenzie *et al*. (2000). It is based on using samples from within a single 25m quadrant to quantify the carbon content of a soil unit. The soil carbon sampling design presented here aims to take into account the spatial variability of soil carbon at the paddock scale. A systematic random sampling strategy was carried out to obtain the carbon data for the whole paddock and to study the factors accounting for the carbon variability. This is part of a larger study is to devise a more efficient and accurate sampling scheme incorporating ancillary information such as crop yield, soil and landscape information (soil ECa, terrain parameters). The results here show that at the paddock-scale there is a decrease in soil carbon content and carbon density with depth. There is also significant, well structured spatial variability across the paddock, and this variability decreases with depth. From this study it is reasonable to conclude that sampling within a 25 m x 25 m square may provide an estimate of carbon within that square but is not likely to provide the detail to accurately monitor soil carbon across a whole paddock.

**Key Words**
Soil carbon, quadrat, bulk density, soil carbon variability.

**Introduction**
The standard method for estimating soil carbon in Australian soils (McKenzie *et al.* 2000) recommends sampling within a 25 m x 25 m square quadrat per soil unit. This technique can quantify C accurately for that quadrat. This has several scientific advantages when comparing the soil carbon levels under different land management practices across paired sites and in soil monitoring programs when soil carbon levels are compared through time (McKenzie *et al.* 2000). However the spatial variation of soil C across a whole paddock is likely to be far greater than the variation within a single quadrat. Therefore the measurement of soil carbon stores at the paddock scale is unlikely to be effectively measured using the standard method of a 25 m quadrat. This has important for the accounting and auditing of soil carbon.
The aims of this study were:

- To quantify and map the spatial variability in carbon density within a paddock and,
- To evaluate the potential errors in using the single 25 m quadrat to predict soil carbon stores at the paddock scale.

This work is part of a larger program to test the effect of different management practices on increasing the soil carbon content in the soil. The overall aim is to ascertain whether variable rate treatments, rather than uniform management practices (Taylor, McBratney *et al.* 2007), would improve carbon sequestration within a paddock,

**Materials and method**
*Study site*
The site, 7east Hatton is in Central West NSW, the governing soil type is a Red Chromosol with traces of manganese and charcoal in the lower depths. There is a depression in the centre of the eastern half of the paddock where the manganese content is high. Clay content increases with soil depth in the paddock and the paddock is under cropping.

*Experimental design*
A 100 m regular grid, aligned with the vehicle tramlines, was overlain on the whole paddock. Random samples were taken within each cell. This systematic random sampling gave 75 sampling points across the paddock. Another 15 secondary sampling points were randomly placed at 10 m or 1 m spacing from primary



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sampling points for an estimation of small scale variability. Sampling points were located using a decimetre accurate Trimble DGPS with Omni star-HP correction.

*Sampling and analysis*

A hydraulic corer mounted at the back of a vehicle was used for the study. The soil cores were cut into 0- to 10, 10- to 20, 20- to 30 and 30- to 50 cm depth increments for the analysis. The soil at the time of sampling was in a moderately moist condition to ensure coherent, intact cores were taken with little disturbance. The depth of the hole from which the core was taken was measured and compared to the length of the core to ensure that no compaction was occurring and that the core reflected the bulk density of the undisturbed soil. The samples were placed in labelled plastic bags and transported to the laboratory for analysis. The samples were weighed and a sub sample was taken to measure the moisture content. The soil was air dried at 40$^{o}$C for 48 h, and passed through a 2-mm mesh sieve. The soil was further grounded to pass a 53 micron mesh sieve. The soil carbon percentages were determined with a CHN –Vario Max CNS analyser. Bulk densities were estimated with the moisture content of sub sample, wet weight and the volume of the core. The carbon percentage values and the bulk density were used to calculate the carbon density for each core in kg/m$^2$. The spatial distribution of carbon density for the whole paddock was estimated using kriging techniques (Whelan *et al.* 2001) from the carbon densities of the individual cores. The spatial distribution of bulk density and soil carbon content were described by global variograms. The total carbon store to 50 cm for the whole paddock (tonnes) was estimated from the kriged spatial distribution of soil carbon density.

*Formula*

CD (kg/m$^2$) = Carbon content (kg/kg) x BD (kg/m$^3$) x Depth (m), where BD is the bulk density and CD is the carbon density.

**Results and discussion**

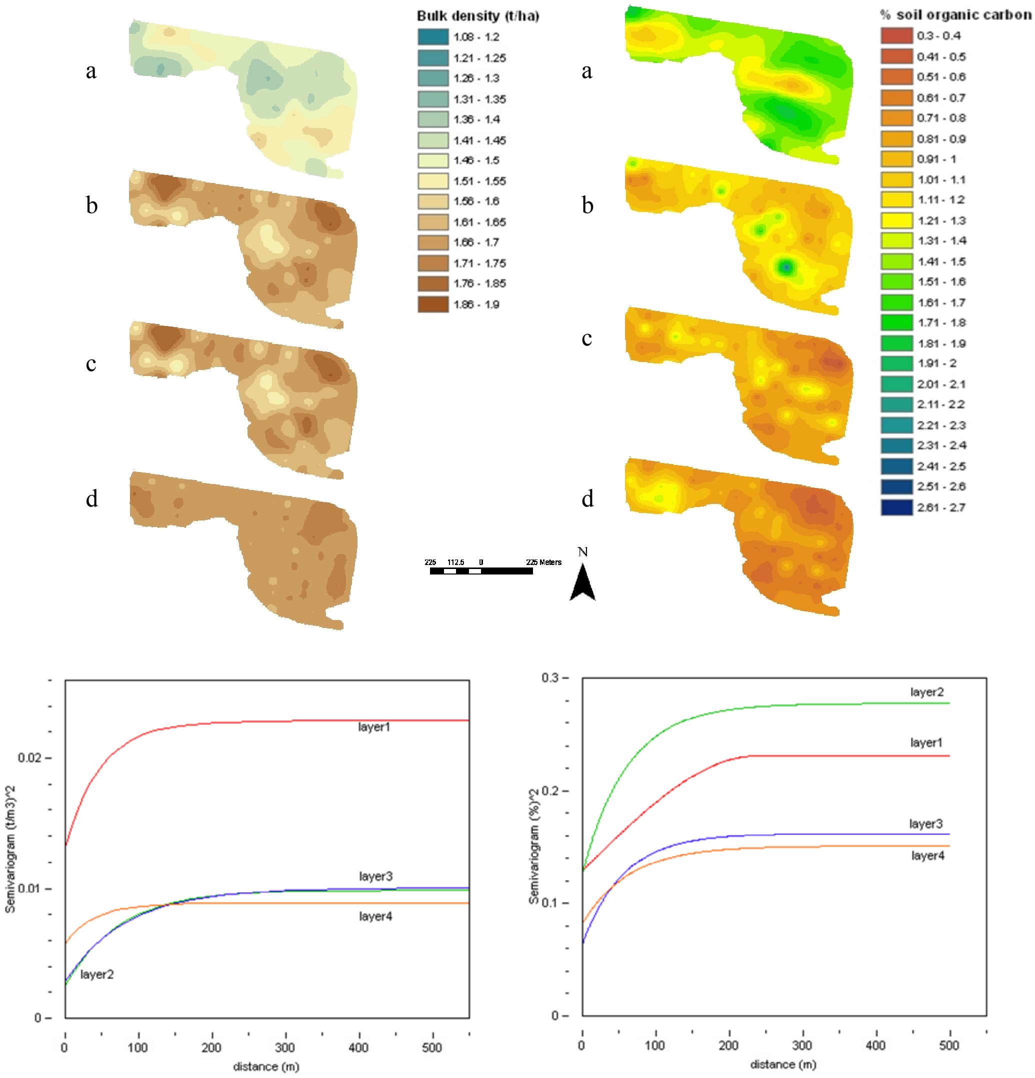
Soil carbon values show a decreasing trend with depth and there is a rise in bulk density with depth. The spatial variation in both properties also generally decreases with depth (Figure 1). Given this data, the calculated soil carbon density also shows substantial variation across the paddock. It varies from 50 to 100 kg/m$^2$/50cm (see Figure 2).

This indicates that the location of a single 25 m quadrat can result in up to 100% variation in the soil carbon density within the paddock and that the selection of the location for the quadrat to measure the soil carbon is a critical decision in estimating soil carbon levels for different land management practices. One advantage however is that there are clearly areas where the soil carbon density is relatively uniform. A potential serious problem for the 25 m quadrat method arises if the quadrat happens to be placed on a location which is a "hotspot" for soil carbon or an unusually low spot, where the critical levels of soil carbon are unusually low (see Figure 3).

The spatial distribution of the soil carbon density based on the grid of soil cores and kriging suggests there are several of these in the paddock. However, as some of these hotspots and unusually low values maybe based on soil carbon values from a single core, this may not necessarily be the case for the standard sampling from a 25 m quadrat which usually includes at least 10 soil cores within the 25 m quadrat. The full analysis of the relationships between the soil carbon densities with spatial information about the paddock including yield data, EM surveys, DEM data, landform analysis etc. is still being processed.

**Conclusion**

Soil carbon density shows significant spatial variability across the study paddock. The random location of a single 25 m quadrat has been shown to be ineffective in predicting the soil carbon store at the paddock scale. It has also been shown that the selection of the location of a 25 m quadrat in the paddock can have a large affect on the amount of soil carbon measured Further analysis will indicate whether the use of such spatial information on crop yields, EM, DEM's, land form and SPOT imagery will enable more effective selection for the location of a single 25 m quadrat to provide information on soil carbon stores for scientific reference sites. This analysis will also enable recommendations to be made about the most effective sampling methods to estimate soil carbon levels at the paddock scale for soil carbon auditing. Future work will also look into using variable-rate management to influence soil carbon at the paddock scale.




Semivariogram of the bulk density          Semivariogram of the soil carbon %

**Figure 1. The spatial variability of bulk density and carbon density within a paddock.**
**Key- a. 0- 10 cm (layer 1), b. 10 – 20 cm (layer 2) , c. 20 – 30 cm (layer 3) , d. 30 – 50 cm (layer 4).**

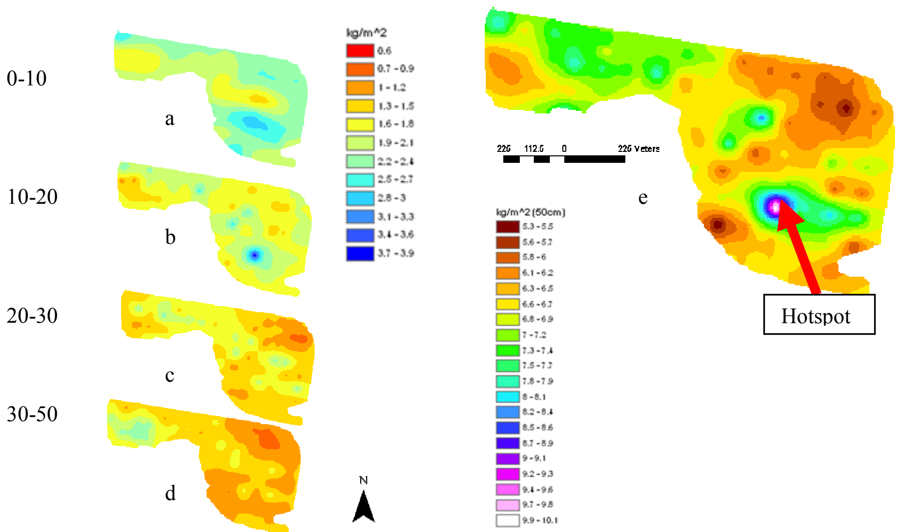



**Figure 2. Carbon density(CD) a.CD at depth 0- to 10-cm, b.CD at depth10- to 20-cm, c. CD at depth 20-30-cm, d. CD at depth 30-to 50-cm and e. average carbon density of the whole profile (50cm) with hotspot. Some caution is required in interpreting hotspots as these are from a single core.**

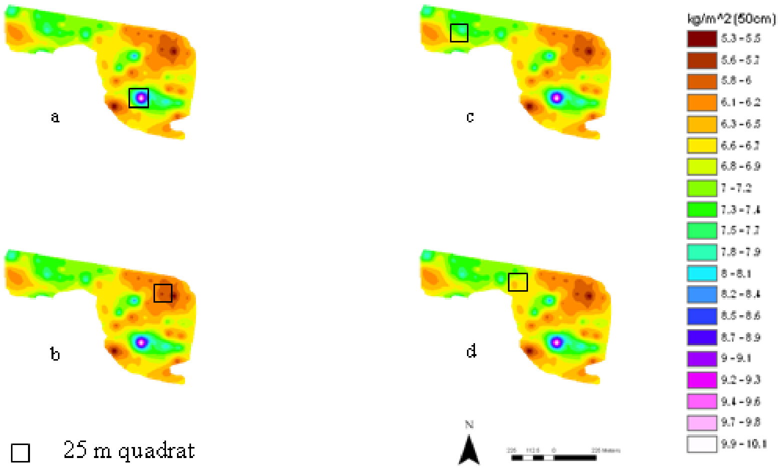



**Figure 3. The 25 m quadrat placed randomly on the paddock a. quadrat covering the hotspot b. quadrat covering the low soil carbon area c. quadrat covering moderate soil carbon area and d. quadrat between the moderate and low soil carbon area.  Ideally the 25 m quadrat should be placed in an area with a relatively uniform soil carbon density.**

## References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