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MEASURING SOIL CARBON

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Abstract

Requirements for monitoring soil carbon are identified. Existing methods that can address the requirements are outlined.

Potential for Carbon Sequestration

Terrestrial ecosystems are attractive for carbon sequestration because they can be managed. The focus has been on woody vegetation, essentially trees, because methods deriving from forestry can provide reasonable estimates of carbon accrual at commercially viable costs. Australia has lead in using trees to sequester carbon because of the potential benefits but Europe still does not accept forestry sequestrations because they do not benefit them.

Soil carbon is now receiving increased attention because of its potential significance but measurement difficulties have limited its value in carbon trading. Protocols already allow for soil carbon in agricultural lands to be included in trading schemes but implementation depends on the availability of cost effective and reliable means of measurement.

An additional issue that affects carbon trading is that the start of 1990 is taken as the reference point for changes. The land must have been cleared of woody vegetation at that time if sequestering carbon through planting trees. For soil carbon an estimate of soil organic matter is required for that date for use as the reference in determining change. The main practical consequence is that degraded land is most suited to obtaining benefits through carbon sequestration as it has greatest potential for increasing soil carbon.

Carbon trading involves the provision of a guarantee that the carbon will remain sequestered for 100 years. This introduces considerable risk with forests because of the potential for tree death through fire and drought. Also, forests are usually harvested. Furthermore, mature forests become sources of CO_2 as the rate of breakdown of plant material eventually becomes greater than is produced. It requires sequential plantings to generate a guaranteed level of sequestration and the sequestration is marginal. Sequestration in forests is best suited to operations where there is ongoing planting in a number of separate locations.

The life of humic compounds in soils is around ten times that of tree carbon, and the amount of soil carbon is on average around double that in live vegetation. An average increase of 2% organic matter to a depth of 30 cm, which is readily achievable in many clay soils, represents a sequestration of 35 tons C / ha, or 128 tons of CO_2 per hectare with an assumed soil bulk density of 1. The amounts compare favourably with levels achievable with forestry.

The greatest significance of increasing soil carbon almost certainly lies in the social benefits by way of the sustainability of farming and the improved nutrition of produce. The viability of the entire society is greatly improved by way of the viability of farming and improved health and well being of all in the society.

More than 75% of Australian agricultural soils are estimated to have levels of organic matter less than 1.75% when desirable levels are in the range of 2 to 8%. Given the large areas under agriculture there is a large potential for carbon sequestration where the long life of humic compounds greatly reduces the risk of inadvertent loss. Moreover, increasing carbon sequestration in agricultural lands provides additional benefits such as increased production, reduced need for inputs such as fertiliser, and reduced environmental impacts such as erosion. Commercial benefits from sequestering soil carbon are supplementary to other benefits that improve the profitability and environmental outcomes with farming.

Carbon trading is only viable where sequestration can be reliably estimated at a cost much less than the value assigned to the carbon. The verification methods must be highly efficient. Verifiable measurements that take account of vertical as well as horizontal patterns of soil carbon are essential.

Table 1. Forms, longevities and relative levels of 'soil' organic matter. Organic matter is around 1.7 times the amount of organic carbon and CO_2 is 3.664 times the amount of carbon.

Location	Form	Longevity	Level (% of above ground biomass)
Soil surface	Litter	days-years	1-10
Below Ground	Roots	days-decades	30-50
	Invertebrates	weeks-months	0.01-10
	Microbes	days-weeks	0.01-100
Soil Organic Matter	Carbohydrates +	days-weeks	0.01-30
	Glomalin	years-decades	0.01-100
	Fulvic acids	years-decades	0.01-100
	Humic acids	100-1000 years	0.01-100
	Humins	100->1000 years	0.01-100

Carbohydrates + A wide range of generally short lived organic compounds that includes carbohydrates, fats, waxes, alkanes, peptides, amino acids, proteins, lipids, and organic acids.

Table 1 lists different forms of organic matter often included in assessments of soil organic matter where many are not part of the soil. Identifying plant roots as part of the soil equates with identifying plant leaves as being part of the atmosphere. Also, the rapid turnover of many components limits their value for carbon sequestration. Components that rapidly decompose can be included provided they are continuously replaced, but this has greater risk than only including long lived components in estimates of sequestration.

Humic compounds are of most consequence as, due to their longevity, they comprise around 70% of soil organic matter. Using humus to quantify carbon accruals represents a low risk. The protein glomalin has been identified as comprising around 30% of soil organic matter noting that it not included in many estimates of soil organic matter. Its levels and longevity can make it significant for sequestration provided it can be cost effectively estimated.

Measurement Issues

The measurements of soil carbon must quantify how much organic carbon has been accumulated over a given period. There is currently no instrument that can be pointed at soils or inserted into them to obtain a measurement of organic matter. Such instruments may eventually exist as organic matter can be reliably measured in the laboratory using reflectance of near infrared radiation, and there is the possibility of using electromagnetic induction, but at present measurement depends on collecting field samples with analysis in the laboratory.

The most cost effective laboratory measurement appears to be infrared reflectance and this provides measurements for different forms of organic matter. For the same cost it also provides other information on soils useful in farm management such as pH, cation exchange capacity and the levels of different clay minerals. Costs are currently $15 per sample for a large number of samples that have been prepared for measurement by drying, grinding and sieving.

Assuming reliable measurement on soil samples, the spatial variability in organic matter becomes the key issues in obtaining reliable estimates for paddocks. Accumulation of soil carbon varies with soil properties, site conditions such as wetness and the type of vegetation, and land management activities such as ploughing. Random collection of field samples is not viable because the resulting high variability introduces large errors in the estimate. High uncertainty in the estimate necessitates a conservative approach of taking the minimum likely level of carbon and this can greatly underestimate the magnitude of the change. The usual approach of analysing one or two bulked samples is similarly inadequate as it does not provide a reliable estimate of error.

The estimates of carbon would normally be developed for management units such as individual paddocks. Archival satellite imagery can be used to examine the land use and paddock condition at 1990. Together with the subsequent management history this provides a basis for relating current soil conditions to those at 1990 provided observations are obtained from numerous paddocks within a region. A range of observations is needed to establish associations between soil carbon and the type of soil, its management and condition.

Within paddocks the sampling should be stratified to take account of variations in soil properties, particularly soil texture, and site conditions. These are often interrelated as site conditions generally relate to land use where this is determined by soil texture. Soil landscape maps cannot address this need as they map mixtures of soils. The main options are to use multi spectral optical imagery, near infrared imagery, thermal imagery, or airborne gamma radiation data (radiometrics) to map patterns of soils.

Near infrared imagery can be numerically analysed to highlight differences in organic matter but is only applicable to ploughed paddocks without litter or plants, and results are affected by the roughness of the soil surface. Thermal measurements are more indirect but can be applicable where there is plant cover as well as bare ground. Due to the occurrence of confounding factors the thermal patterns are generally visually interpreted. Daytime thermal imagery is less useful than nighttime imagery but the latter is seldom available. Nighttime thermal imagery can be obtained from satellites but has not been routinely acquired because the satellite has to operate on batteries.

The radiometric measurement reflects patterns of soil properties and requires numerical analysis to provide paddock level detail. With appropriate analysis the radiometrics provide paddock level mapping of patterns of soil properties across regions. While they provide the most useful information airborne radiometric data are only available for a few cropping areas.

The fall back position involves the use of satellite imagery. This can be used to map variations in clay and other mineralogical variations such as ferric and ferrous ions, particularly where there is considerable bare soil, but the results are visually interpreted on a paddock by paddock basis as they are affected by the level of exposure of soil.

The image data are used to stratify paddocks into areas with similar soil characteristics. Sufficient samples are then taken from the different areas of soils to quantify the level of soil organic matter and its variability. Soil samples can be bulked to reduce the variability provided the sampling regime gives a reliable estimate of error. The advantages of bulking samples are the reduced number of laboratory analyses and the reduced variation. The sampling has to encompass different soil depths as most gains arise through the increase in depth of organic matter within the profile.

The significance of changes in organic matter with soil depth effectively precludes the use of remote sensing techniques to directly provide reliable estimates. Remote sensing serves only to provide a basis for stratifying the field sampling. While electromagnetic observations can be obtained remotely the shallow depths involved necessitate ground sampling.

Increasing the soil organic matter increases the soil depth as organic matter has a density around one quarter that of the mineral soil, and it aggregates soil particles. An increase in organic matter therefore usually reduces the soil bulk density. This reduction in bulk density is countered, but is unlikely to be exactly balanced by, the increase in soil depth, hence the changes in bulk density must be addressed when deriving quantitative estimates. With further knowledge the bulk density estimates may not be needed but that will depend on circumstances.

Effects of soil depth are addressed by sampling soils at different depths. These provide measures of the amount of carbon per unit weight of soil. Estimates of bulk density are used to convert these gravimetric estimates into volumetric estimates and hence the total mass of carbon. Soil sampling using corers allows calculation of the bulk density when samples are dried (mass of soil per unit volume) but, while corers are effective with many farm soils, they are not with dry clays and soils containing gravel.

A less precise but practical approach to measuring bulk density is to use specifically designed augers that cut a neat hole. Estimates of bulk density can then be simply obtained for each sample where the number of samples compensates for any loss of precision. However, the suggested loss of precision may be insignificant as estimates of bulk density obtained using augers when installing neutron moisture tubes have been reliably used to obtain estimates of the soil volumetric water content. As variations in soil bulk density are much less than for soil organic matter the reliability of estimates should not be limiting.

Conclusions

The general conclusions are that:

- There is appreciable potential to sequester carbon by increasing the levels of soil organic matter.
- Changes in soil organic matter can be reliably quantified.
- Sequestration is attractive because of the long life of many compounds.
- Sequestration is also attractive because of the associated benefits to farm profitability and environmental outcomes.

There are many good reasons for farmers to increase soil organic matter but the question of whether to become involved in carbon trading resolves into a risk – benefit analysis. The costs include the development of appropriate land use and soil maps, and the ongoing sampling and measurement of soil carbon. Actual costs can vary considerably depending on the approach as field sampling represents more than half the cost of a soil survey. Conduct of sampling by farmers can reduce costs provided checks are embedded to meet verification standards.

The promised monetary benefits may be appreciable but caution is needed in committing to a sale with a 100 year guarantee in a trading system that is just being established. Promises do not necessarily become reality. Moreover, prices for carbon in Europe are generally higher than in Australia and any carbon losses have to be met by buying carbon on an expected increasing market. The risks may be small with good management but the risk of not maximising the return currently appears to be high to the point of being a certainty.

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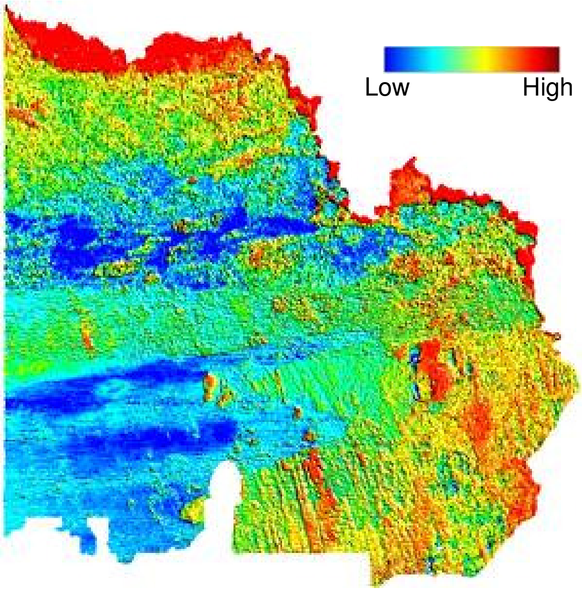
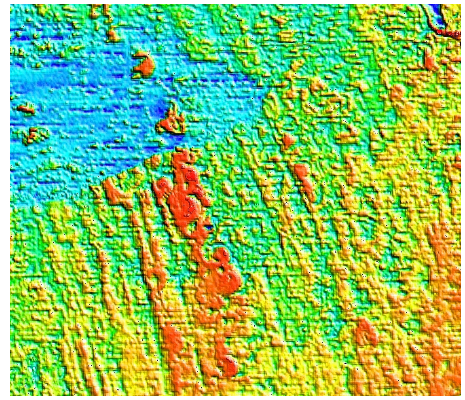
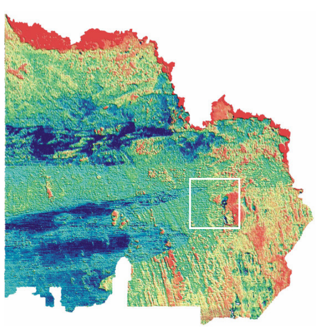
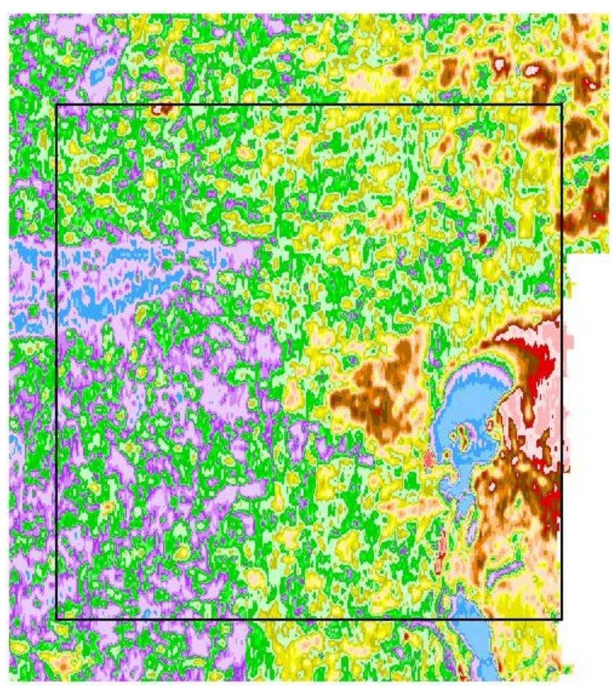


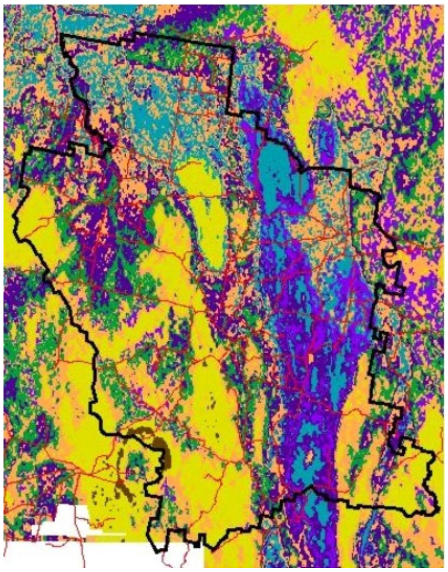


Soil Landscape Mapping using Radiometrics
(Edge enhanced raw radiometric image (total count) of the Mallee Region, NW Victoria compiled by aggregating surveys for different areas)
Sand dunes are blue and clay is red.
The image differentiates the surficial geological formations of:
Parabolic dunes of the Big Desert (blue in the SW).
Mixed dunes of the sunset country (blue to the north).
Parallel dunes of the Woorinen Formation (between the Sunset and Big Desert formations)
Remnant beach ridges of Parilla Sand to the SE (expanded in the right image)
Sand hills in the northern part of the Sunset Country.
Quaternary riverine alluvium along the Murray River

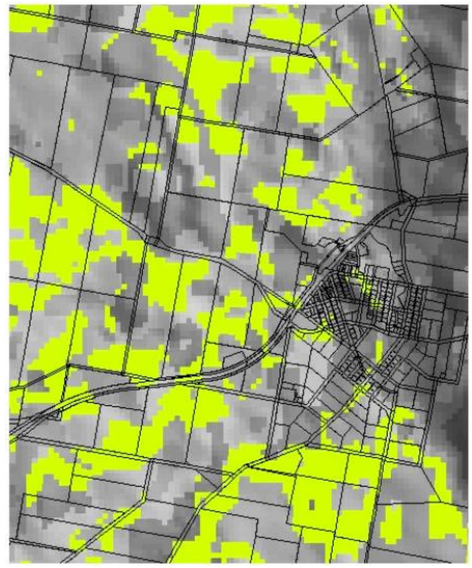


Soil Variation Map for Part of the Mallee Region
Map produced by classifying the raw radiometric data for K, U, Th and TC.



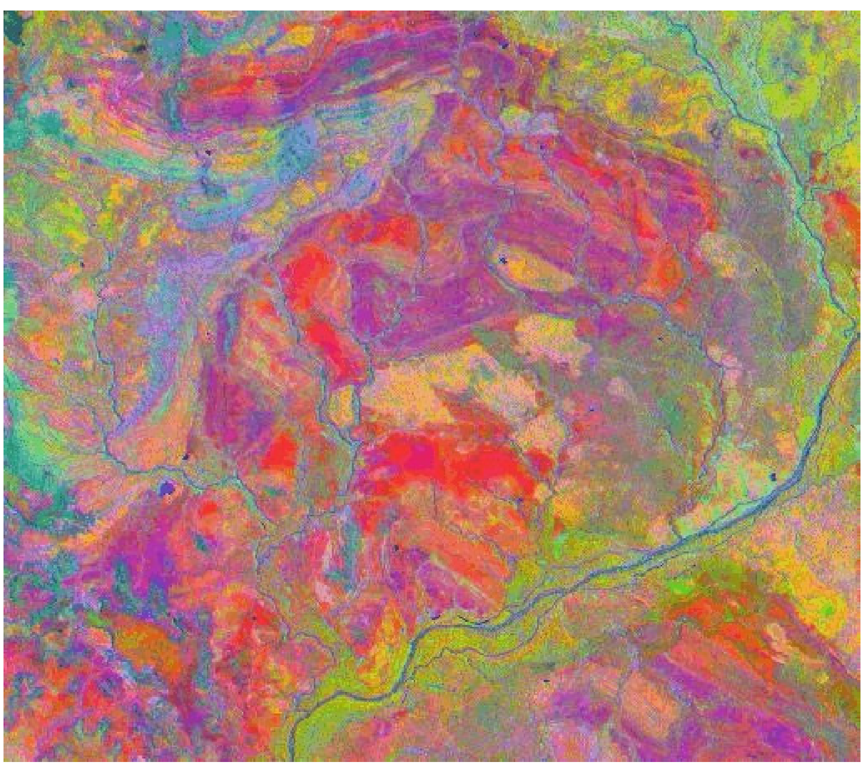


Map of the texture of the B soil horizon derived from radiometrics. Regional coverage for the Cootamundra Shire.
Soil textures are colour coded ranging from sandy clays (green) to heavy clays (dark blue)

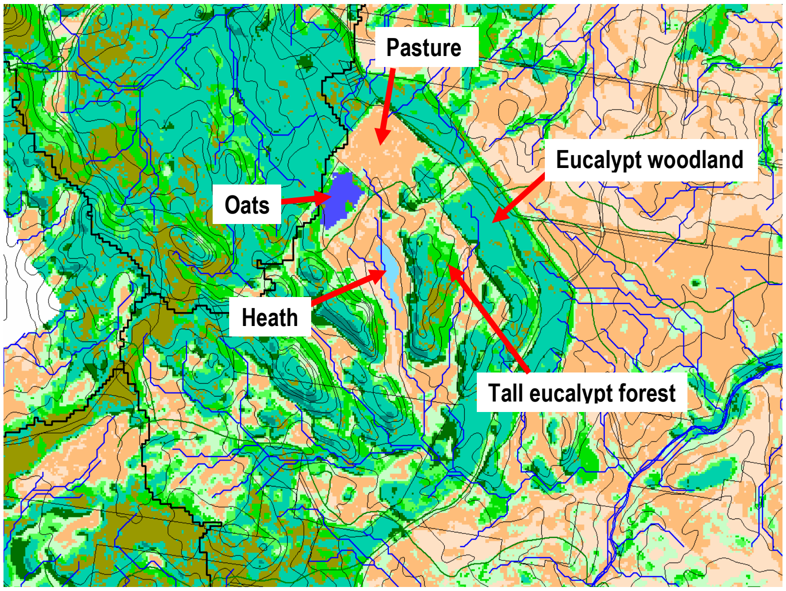


Soil Selection, Wallendbeen.
Paddock level detail in the regional soil map derived from radiometrics.
Soils having B2 horizons with:

- Silty clay to medium clay
- Pe/pH ratio 1.1 - 1.4
- Depth to B2 > 50cm
- Minimal dispersibility



Mineralogical analysis of a satellite image, west of Townsville
Red - ferric
Green - ferrous
Blue – clay
The area is geologically complex but the alluvium associated with the river is readily identified.



Landcover map derived from a classified satellite image
The vegetation is colour coded for mapping. Areas of **w**oodlands and forests are painted green, grasslands brown, and crops blue.

Development of soil organic matter through land management