Soil testing protocols at the paddock scale for contracts and audits

Market-based instrument for soil carbon

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More information

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Contents

Foreword

The Project “Market-based instruments for soil carbon – achieving soil health targets” was funded by Catchment Action NSW towards the end of 2009 when significant uncertainty existed around the agriculture sector’s role in climate change mitigation. The aim of the project was to fill a number of important gaps in current land management policy through the design and implementation of a MBI to enhance soil carbon sequestration. The pilot was implemented with the support of the NSW Department of Primary Industries, the NSW Office of Environment and Heritage and the Lachlan Catchment Management Authority from 2011 to 2012 (Lachlan CMA 2011). Farmers were funded through the MBI to adopt land management actions with the specific aim of increasing soil carbon. The pilot project concentrated on a small part of the catchment on a defined area with a specific climate and soil type.

The implementation of carbon trading schemes or market-based instruments (MBI) for soil carbon requires accurate estimates of the status and change of soil carbon stocks. Such schemes often perform soil carbon budgeting at the farm-scale. However the paddock or field tends to be the natural management unit of a farm and therefore the effects of management practices on soil carbon stocks should be quantified at the paddock-scale or field-scale. Soil carbon stocks can vary greatly within a field according to locally variable factors such as plant growth, soil texture, drainage conditions and landform. This means that a substantial number of measurements and hence financial resources might be required to produce estimates of the field-mean with acceptable precision. Therefore the cost-effective sampling of carbon at the field-scale is a pressing problem.

This methodology was jointly developed through discussion among the authors and some preliminary trials of time requirements and practicality of different strategies. It is a protocol to estimate the soil carbon levels for paddocks or fields. The authors do have a broad practical and theoretical experience in the problems and challenges of measuring soil carbon. Existing literature on the subject and statistical advice was also sought from a range of sources.

Part 1.

Overview - Background and rationale behind the protocol

1.1. Introduction

A joint project between Industry and Investment NSW (I&I NSW), the Office of Environment and Heritage (OEH, formerly Department of Environment, Climate Change and Water, DECCW), and the Lachlan Catchment Management Authority commenced in 2009 that aimed to design and pilot a market-based instrument (MBI) that supports land managers to adopt practices that increase soil carbon. The project was implemented in central west NSW in cooperation with the Lachlan Catchment Management Authority. The purpose of the pilot project was to test a methodology for trading in soil carbon under realistic trading conditions. The title of the project was abbreviated to be called the CAMBI project, based on a carbon MBI.

The MBI involves a form of reverse auction where farmers bid for incentive funds to make soil carbon–positive land management or land use changes. Contracts were either ‘Actions’-based, where payment was made for pre-determined actions with pre-set soil carbon sequestration rates, or ‘Outcomes’-based, where payments were determined by measured soil carbon changes over 5 years. The latter contract option required a higher level of measurement accuracy to determine the actual change in soil carbon over time.

One of the key challenges associated with soil carbon sequestration concerns the measurement of changes in soil carbon stocks at a paddock level. These are well documented and arise because:

- soil carbon contents can be highly variable even within a paddock;
- there are differing degrees of permanence of different forms of soil carbon;
- annual changes in stocks arising from alternative practices are small compared to the existing carbon stock, particularly over short time scales; and
- many site-specific factors influence the response of soil carbon to changes in practices (e.g. climate).

The successful functioning of the scheme required an effective method to estimate soil carbon levels at the paddock scale that addressed these difficulties. This protocol was developed for this purpose in the pilot project and relates specifically to this project.

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1.2. Basics

Sampling soil carbon for a MBI for carbon trading requires an emphasis on estimating soil carbon at the paddock scale or sometimes over a number of paddocks. The use of a single 25 x 25 m quadrat to estimate soil carbon, as advocated in several protocols for measuring soil carbon (McKenzie et al. 2000; DECCW 2009; Wilson et al. 2010; Sanderman et al. 2011), is not a sufficiently robust method to estimate the soil carbon store or changes in soil carbon stores over time at a paddock scale. It is essential to emphasise that these protocols were not specifically developed to estimate soil carbon at the paddock scale.

They were set up to specifically keep the sampling areas small and homogeneous to assist in detecting differences between paired sites and as a monitoring tool to detect differences between times, or as representation of different management systems to look for management differences between paddocks (McKenzie et al. 2002; DECC 2002; Wilson et al. 2010; Sanderman et al. 2011). While many schemes exist to monitor soil carbon, the most appropriate one for each individual circumstance will be defined by the specific questions being asked and the scale over the soil carbon is to be estimated. To estimate the soil carbon store for a paddock, a single 25 m quadrat is clearly inadequate, although a series of such quadrats strategically placed may be appropriate.

For the purpose of the CAMBI project the sampling scheme was designed to achieve the following two objectives.

- Estimate the initial level of the soil carbon in a paddock or set of paddocks being assessed for a contract.
- Estimate the change in soil carbon between the initial and the final soil carbon store after management actions have been undertaken on the paddock(s) as part of the contract. The change is estimated at the second measurement after five years or some defined time period.

It is important to note that in developing sampling strategies, these two objectives maybe in conflict and compromises are required. For example a strategy that provides the best capacity to estimate the soil carbon store of a paddock may reduce the statistical power for detecting changes in soil carbon over time and the reverse applies as well.

The objectives of this sampling program need to be clearly understood as any sampling program will be constrained by the following:

- The changes in soil carbon over a short period of time are often near the limits of detection due to the large natural variation in soil carbon across a paddock (CV > ≈30%) (McKenzie et al. 2002) caused by changes in landform or soil type and the small expected annual changes associated with most changes in land management practices,
- The changes in soil carbon over a short period of time are often near the limits of detection due to the large natural variation in soil carbon across a paddock (CV > ≈30%) (McKenzie et al. 2002) caused by changes in landform or soil type and the small expected annual changes associated with most changes in land management practices,

The high cost of sampling will be a major part of the transaction costs in any MBI for soil carbon.

To address these issues, statistical principles and knowledge need to be used to account for the spatial variation in soil carbon and to detect changes in soil carbon over time.

1.3. Sampling strategies

The sampling strategies in this protocol have been designed for two specific purposes. Phase I of the protocol was designed to be a low-cost strategy to estimate the soil C store of sites of land holders who wished to participate in the soil C pilot. The method was designed to be quick and low cost so is not accurate enough for estimates to be used as a base-line measurement for outcomes and hybrid contracts. Phase II of the protocol was designed to collect base-line and final data, respectively, on the soil C stock to determine the amount of additional soil C stored over the five-year contract period for successful contracts. The guidelines and concepts behind the development of each strategy are detailed below.

Phase I: Sampling at the initial site visit

- *Estimate of current soil carbon store at a site.*
- *Soil carbon store used in the bid process.*
- *Soils sampled 0-10 cm using 10 quadrats, but more if area is larger than 100 ha. Soil carbon percentage measured.*
- *10 cores taken and bulked within each quadrat.*
- *Soil carbon store to 30 cm estimated using pedotransfer function developed specifically for the soils within the Cowra Trough Red Soils Cropping Belt.*

Phase II: Sampling for outcomes and hybrid based contracts

- *Requires higher level of accuracy.*
- *Estimates of soil carbon levels at start of contract and then at completion of contract after 5 years.*
- *Payment of contract based on increases in soil carbon after 5 years.*
- *Soils sampled 0-30 cm using 10 quadrats, but more if area larger than 100 ha. Soil carbon percentage and bulk density measured to obtain measurement of soil carbon store to 30 cm.*
- *Measurement requires taking soil cores to 30 cm and measurement of bulk density.*
- *8 cores taken and bulked within each quadrat.*
- *Audit sampling - A random set of sets across the paddock of 0-10 cm samples maybe undertaken.*

1.4. Guidelines for sampling

Some general principles for the sampling protocol at the paddock scale are outlined in Table 1 and an example a sampling strategy for a hypothetical paddock is shown in Figure 1. These principles were developed using field experience as well as reviews such as those of Allen et al. (2010) and the guidelines in publications such as Webster and Burgess (1984), Brus et al. (1999), McBratney and Pringle (1999) and Simbahan et al. (2006). These guidelines are discussed in more detail below.

Guideline 1. Stratification of a paddock using associated features that affect soil and soil carbon distribution

Soil carbon has been shown to be influenced by features such as landform, rock outcrop, soil texture, soil fertility, land management history and geology at the paddock scale. Therefore paddock stratification is generally recommended prior to undertaking a sampling program. Stratification is used primarily to determine relatively homogeneous zones of soil in a heterogeneous landscape, and to account for the relative extent and distribution of these zones. This was done visually on-site with assistance from soil and geology maps and remote sensing tools with aerial photographs and satellite images. This was done on the initial Phase I site visit.

In summary, the paddock was stratified according to existing soil and geology maps and one or more of the following features which were observed in the field or using aerial photography:

- landform (crests, midslopes, footslopes, depressions)
- soil type
- rockiness and outcrop
- abundance of trees
- land management history if this is known to be different, as will often be the case with sites in which several paddocks are included or can sometimes be within a single paddock e.g. stock camps, shade areas water points etc.

- Any other factor likely to result in changes in soil type and changes in soil carbon levels (e.g. sheet erosion and deposition).
- The outcome was that within the paddock, there are stratification units that are relatively uniform in soil type, landform, geology, and land management history.

Table 1

Guidelines for estimating soil carbon stores and changes in soil carbon stores at the paddock scale
Soil carbon has been shown to be influenced by features such as landform, rock outcrop, soil texture soil fertility and geology changes. The stratification of the paddock using these features is essential. This can be done by field assessment, remote sensed images or digital mapping methodologies.
The stratified units within paddocks need to be further stratified to produce a series of equal areas within which the random sampling points are chosen. The number of equal areas will be the same as the number of sampling points to be measured. This conforms to the sampling strategy advocated by Brus et al. (1999) who suggest the precision of estimates at the paddock scale is increased by spreading the sampling points over the field.
It is necessary to measure the initial soil carbon store of a paddock. It is very difficult and there is a high level of uncertainty with estimates of soil carbon stores based on land management history or modeling previous land management to obtain an estimate of the soil carbon stores on a paddock. A pedotransfer function is utilised to estimate the soil carbon stores in the initial assessment of bids. In this rapid process 10 cores were taken per quadrat. However, for any Outcome-based contracts, more formal measurements of the soil carbon stores are made.
The sampling time will be standardized to a prescribed time within the cycle of the land management actions and the seasons. For example, the time between harvest and the first cultivation prior to the next crop is a logical window for sampling in cropping paddocks and autumn is a logical window for sampling grazing paddocks.
For the formal process of estimating the soil carbon store for Outcomes–based contracts, the basic sampling unit, which equates to a sampling point, will be a 40 m quadrat. Samples from this quadrat will be bulked for analysis and as a standard 8 cores will be taken from each quadrat for bulking. Samples will be bulked within each depth layer. Other critical points in relation to the quadrats: • Within each paddock, results to date suggest at least 10 such quadrats will be required to estimate the soil carbon stores. For areas of more than 100 ha or of more complexity, more quadrats will be required. • The use of the quadrats maximizes the capacity to detect changes in soil carbon stores over time based on: • The 40 m quadrats are sufficiently large to allow for re-sampling a second time At the agreed final measurement time, the quadrats can be analysed as paired sites which greatly increases the resolution of any statistical analysis to detect significant changes in soil carbon stores.
It is proposed that the level of probability accepted as “significant” for the difference in soil carbon levels between the initial and second soil carbon sampling is not necessarily 5 per cent. Lower levels of significance maybe sufficient.

The outcome was that within the paddock, there are stratification units that are relatively uniform in soil type, landform, geology, and land management history. Alternatively the stratification of the paddock can be undertaken as a geostatistical process using GIS and statistical relationships or associations with land form (digital elevation models), radiometrics, electromagnetic surveys, satellite images and a range of other remote sensing tools. These are broadly referred to as digital soil mapping methods. Generally the use of external or remote sensing and landscape digital data has been used to predict soil carbon levels at the whole farm and the regional scale, but less often at the paddock scale. Simbahan et al. (2006) used slope, surface reflectance, elevation and electrical conductivity to stratify the paddock for sampling. This allowed a reduction in sampling costs without a loss of information about soil carbon. A similar approach was taken by Miklos et al. (2010) to estimate soil carbon levels at the farm scale, but they also utilised radiometrics to stratify their study area. The usefulness of such remote sensing tools can be variable at the paddock scale because many of the methods are more suited to the total farm and especially the regional scale. Their use at the paddock scale can potentially be limited by the overriding effects of land management (Bell and Worrell 2009) or by the need for very high resolution data to obtain meaningful relationships at the paddock scale (Hancock et al. 2010).

Guideline 2. Further splitting of the stratification units into areas of equal size

The stratification units developed in Guideline 1 needed to be further subdivided to maximise sampling efficiency. In this sampling scheme, a good coverage of the paddock is best achieved by splitting the paddock into blocks of equal area from which random points are chosen. The sampling design split the stratification units formed above into the same number of equal area blocks as the number of random points required to be sampled. The points are then randomly selected within each of the equal areas (see Figure 1). This procedure is termed “Stratified Simple Random Sampling” (Brus et al. 1999). Brus et al. (1999) estimate that this procedure increases the precision of estimates from the sampling, especially if the variograms indicate the range is long and the nugget/sill ratio is low, as is often the case with soil carbon (McBratney and Pringle 1999; Simbahan et al. 2006).

Guideline 3. It is necessary to measure the initial soil carbon levels in a paddock

For an individual site / paddock it is very difficult to predict the soil carbon store based on previous land management information alone, either from general land management - soil carbon relationships, or using soil carbon modelling. This is because:

- It is unlikely that a single, well defined land use – land management regime has been implemented on the site for sufficient time for a long term equilibrium level to have been reached. Most likely, because of economic, agronomic and personal reasons, a series of different regimes will have been implemented for short time periods, probably too short for an equilibrium level of soil carbon to have been established under any of these regimes.
- It is very difficult to obtain sufficient information from the land manager about previous practices to define the land use-land management regimes with sufficient detail to predict soil carbon levels with high degrees of confidence and the spatial influence of management practices, particularly grazing.
- The presence of unknown amounts of resistant soil carbon as charcoal or char which are not affected by changes in land management add an extra level of uncertainty.

As a consequence, in order to obtain a paddock estimate of the initial soil carbon store, the only reliable way is to use actual measurements of the soil carbon store.

For the initial bid assessment process (Phase I in the Sampling Protocol), to minimise transaction costs, a pedotransfer function developed for the Cowra Trough Red Soils was used to obtain estimates of the initial soil carbon stores. Without this approximation, the transaction costs of assessing all the bids would have been prohibitive. The pedotransfer function used the 0–10 cm soil carbon content (TOC per cent) to estimate the soil carbon store to 30 cm (Murphy et al. in prep.). The pedotransfer function was highly locally specific and only applies to the targeted soil. For any Outcome-based contracts that are granted within CAMBI, actual measurements of the 0-30 cm initial soil carbon stocks were made (as described in Phase II of this Sampling Protocol).

Guideline 4. Standardised sampling time

The sampling time was standardized to a prescribed window of opportunity within the season and land management actions of the management systems being undertaken on the paddock. For example the time between harvest and the first cultivation prior to the next crop is a logical window of opportunity in a cropping land management system. Early autumn maybe a logical time for sampling pastures. The object is to minimize the impact of temporal variability in soils on the results of any soil carbon measurements. It may be possible to use other standardized times through the growing season, but the time between harvest and the first cultivation on a settled seedbed was a convenient and effective time for paddocks under cropping.

Guideline 5. Sampling program for any outcome-based contracts in Phase II

a) The Basic Sampling Unit at each random point was a 40 m Quadrat.

b) Samples within the quadrat were bulked at each depth layer.

c) For each paddock 10 quadrats were sampled.

e) Re-sampling at the completion of the contract to test for changes in soil carbon will be done on the same quadrats.

The basic sampling unit, which equates to a sampling point, was a 40 m quadrat. This is an area of ground 40m x 40m square. Samples from this quadrat were bulked for analysis at each depth and as a standard, 8 cores were taken from each quadrat for bulking. The advantage of bulking the samples from the quadrat is to smooth out the short range variation in soil carbon and increase the probability of finding changes in soil carbon levels with time (Webster and Burgess 1984; Allen et al. 2010; Conant and Paustian 2002; Goidts et al. 2006). The short range variation in soil carbon within 100 m can be substantial (McBratney and Pringle 1999; Simbahan et al. 2006) and to remove this overall variation from the data set can result in improved predictions of soil carbon at the paddock scale.

Although information is limited, the recommendation was that 10 quadrats (termed "sample points") were required for each paddock to estimate the soil carbon store for the paddock. While considerably more research is required to confirm this as an adequate number of samples to give the necessary certainty on soil carbon stores, 10 samples for paddocks up to 100 ha is advocated as a standard until better information is available. For paddocks larger than 100 ha the number of quadrats to be sampled increases by approximately 1 every 10 ha. Paddocks with a high degree of complexity in landform, soil, geology or land management and sites with multiple paddocks may also require more random points. Note that the location of the quadrats is defined in the location of the random points in Guideline 2.

While the 25 m quadrat is advocated as a standard elsewhere (McKenzie et al. 2000; DECCW 2009; Sanderman et al. 2011), the recommended expansion of the quadrat size beyond the standard 25 m is for the following reasons:

- The spatial scale of variation in soil carbon is frequently at about 100 m (McBratney and Pringle 1999; Simbahan et al. 2006). Hence there is a case for expanding the size of the quadrat to take account of more of the short range variation in soil carbon. Wilson et al. (2010) have suggested that the variability of a 25 m and 40 m quadrats are the same statistically. However, when a whole paddock design is applied it can be shown that the 25 m quadrat is not the same as a 40 m quadrat. In fact the larger the quadrat, up to at least 100 m, the more of the short range variability that is accounted for in the sampling design (Sing et al. accepted). This is to be expected given the published variograms on soil carbon showing that carbon often has a range of about 100 m (McBratney and Pringle 1999). However there are disadvantages in a larger quadrat. The increase in variability may make it more difficult to detect changes in soil carbon over time and a quadrat larger than 40 m becomes practically difficult to manage. It is important to consider whether a larger quadrat may allow a more accurate prediction of the soil carbon store on the paddock, yet sacrifice some capacity to detect differences in soil carbon over time.
- The quadrats are sufficiently large to allow re-sampling for the final soil carbon measurement. At the agreed final measurement time the same 10 quadrats are to be re-sampled (using different random sites within the quadrats) to allow the 10 quadrats to be analysed as paired sites compared to the initial soil carbon measurement. This greatly increases the resolution of any statistical analysis to detect significant changes in soil carbon stores between the initial soil carbon levels and the final soil carbon levels.

One limitation of returning to the same quadrats to make the soil carbon measurements at the end of the contract is the potential for “gaming” or the application of “special management” to the quadrat sites. This requires the implementation of an audit procedure to test for the possibility and minimize the risk of this occurring. The audit process involves a random sample of 0–10 cm samples taken outside the quadrat sites.

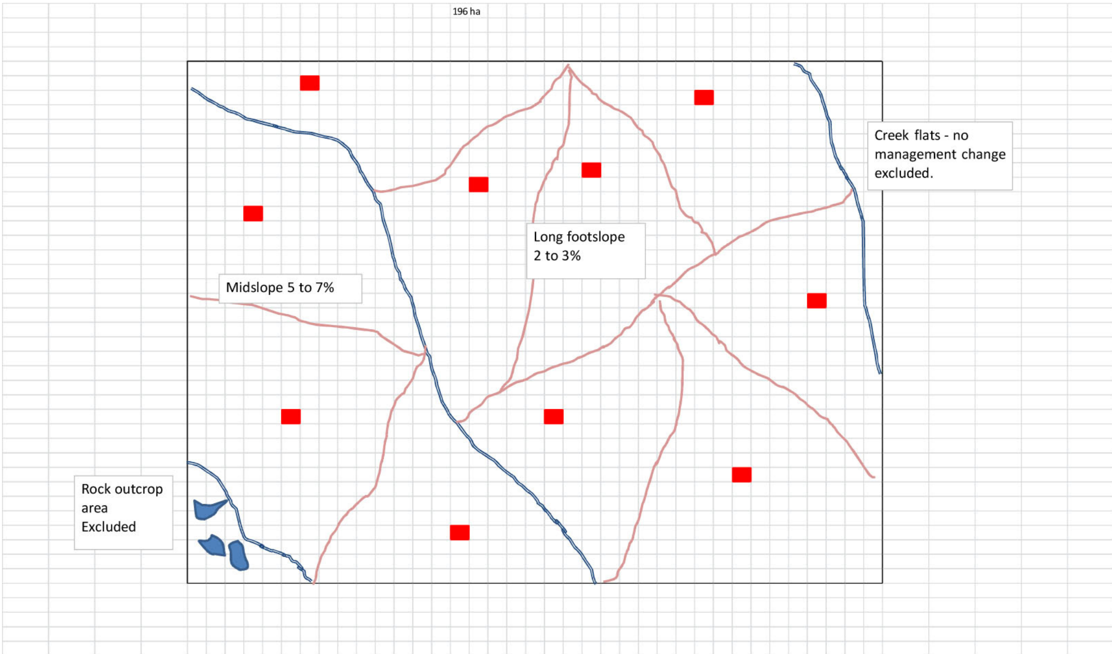
- The grid system of setting potential random points within a quadrat (McKenzie et al. 2000; DECCW 2009; Sanderman et al. 2011) was not adopted here due to cost. There is a substantial time cost in setting up such a grid (Singh et al. accepted). For this reason a radial system selecting random points within a quadrat has been adopted. Details of the radial system are presented on page 19 in Figure 2. Data collected during other projects has shown a radial system to be much more time efficient and it is generally considered that there is little loss in statistical efficiency in terms of the randomness of the location of the cores within the quadrat.

An important issue is whether the priority of the sampling strategy is to estimate the soil carbon store in the paddock or is it to detect changes in soil carbon store over time. Slightly different sampling strategies can be advocated depending on the priority (Lark 2009). In this case, the priority chosen is to detect differences in the soil carbon store over time. If the priority was to estimate the soil carbon store over the entire paddock, the sampling strategy would have been to select a new set of quadrats for the second time of sampling. The new set of quadrats would have increased the area of the paddock sampled for soil carbon increasing the confidence in the estimates of the soil carbon store for the paddock. On the other hand, this would have reduced the statistical power of comparing the soil carbon measurements at the two different times because it would not have been possible to apply the paired t-test to the quadrat data.

Guideline 6. Accepting a lower level of significance than 5 per cent

The concept of statistical significance is based on probability. It is convention that a 5 per cent probability of an event occurring by chance is considered “significant”. While this has been shown to be a very effective convention for reporting scientific results which are going to presented as a general rule, under the conditions of carbon trading where the events are one-off, individual events that are not going to be promoted as a general rule, it can be argued the 5 per cent probability of an increase in soil carbon having occurred is perhaps too restrictive. It is proposed that the level of probability accepted as “significant” for the difference in soil carbon levels between the initial and second soil carbon sampling is not necessarily 5 per cent. A trader may be prepared to accept a 10 per cent chance that a particular land holder has not sequestered soil carbon. This is a policy and an economic decision as much as a scientific decision. Hence the amount of risk that a trader is prepared to accept in trading in soil carbon will not automatically be the standard scientific 5 per cent, but some other probability risk determined by policy or economics. However the scientific data is required in order to quantify the risk.

Figure 1 An example of a sample design for a paddock that is 100 ha with 28 ha of midslope and 65 ha of footslope. Areas of rock outcrop and creek flat are excluded. The midslope area is divided into 3 equal areas and three 40 m quadrats chosen at random within the equal areas as shown. The equal areas can be generated by GIS (preferred) or approximated manually. Similarly, seven 40 m quadrats are chosen within the footslope area. Within each quadrat, 8 cores are sampled and the soil bulked at each depth (i.e. all 0-10 cm bulked, 10–20 cm bulked and 20–30 cm bulked).



1.5. Conclusion

The sampling protocol to determine soil carbon stores at the paddock scale had two major aims: the estimation of the soil carbon store of the paddock; and secondly the detection of changes in soil carbon levels over time. Minimizing transaction costs and achieving these objectives will be a major challenge for any sampling protocol. This current sampling protocol has been developed to achieve this based on the existing level of knowledge about soil carbon. Future improvement in the knowledge about spatial distributions of soil carbon and sampling techniques are likely to lead to improvements in this protocol.

Part 2.

The protocol applied for paddock scale sampling in the CAMBI pilot project.

Phase I - A. Sampling for initial site visit

Applied for all bids and for all possible contracts

A1 Field operations

1. Identify the target paddock or target area on a SPOT image or on an ADS40 air photo image if available. The image should be GIS compatible.
2. Identify details of differences in soil types and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type, differences in paddock history, and internal fences. Property maps and land management discussions with the landholder using aerial photos can be valuable aids. A site visit can be used to assist with this mapping and identifying the important features of the paddock or target area.
3. Stratify the paddock and/or target area to be sampled. The target area may a single paddock or in some cases it can be a series of adjacent paddocks. The stratification can be based on factors such as:
    a. landform (crests, midslopes, footslopes, depressions)
    b. soil type
    c. rockiness and outcrops
    d. abundance of trees
    e. land management history if this is known to be different, as will often be the case with sites in which several paddocks are included or can sometimes within a single paddock e.g. stock camps, shade areas water points etc.
    f. any other factor likely to result in changes in soil type and changes in soil carbon levels (e.g. sheet erosion and deposition).
4. Outline the areas identified as the stratification units on the GIS image (SPOT or AADS40).
    a. Determine how many of the 10 points are required within each stratified area. A suggested methodology is to assign points as a proportion of the area. If the area of the paddock or the site exceeds 100 ha then add 1 sample point per 10 ha.
    b. Each of the stratified areas is then divided into “n” equal areas where “n” is the number of random points to be sampled. Draw polygons around each of these equal areas.
    c. Select the function to choose random points within each polygon depicting the equal areas. Select a random point within each of the equal areas plus up to 2 extra points in case of rejection of sites for reasons outlined in Item 9. If the random points are too close to a fence or land on an obvious headland it is better to choose another random point using the GIS rather than spend expensive field time locating a point only to reject it.
    d. Record the coordinates of the random points selected by the GIS function in latitude and longitude. If Eastings and Northings are used, ensure note is taken of the projection in use so no errors occur when they are transferred to the paddock.
5. Locate points in paddock.

6. Examine each site to confirm it is the target soil type. Exclude points that have alluvial soils or depressions, basalt and very sandy soils (sandy loam or sandier). A hole may need to be dug to a depth 30-40 cm at 2 to 3 locations to confirm soil type.
7. Once a site has been confirmed, the inspection person will either mark on an aerial photo or a paddock sketch map to show soil type differences and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type and internal fences not already recorded. Producer property maps and discussions with them will be extremely useful to assist with mapping.
8. Soil samples will be collected from the 10 sampling points. Sampling points will avoid the following:
   a. Headlands,
   b. Stock camps,
   c. Areas near trees (unless trees are a normal part of the area to be sampled)
   d. Any other areas showing obvious signs that they are an unusual part of the site e.g. Erosion and deposition areas, areas of excessive trafficking from harvesting.

   The rejection of sites needs to be done with some care. Sites should only be rejected if it is clear they are small, unrepresentative areas of the paddock. As a general rule, the area to be rejected should be substantially less than 10 per cent of the paddock and more specifically, 10 per cent of the paddock that is going to be subject to changes in land management and included in the carbon contract.
9. A GPS reading set on GDA 94 or WGS 84 will be taken from the centre of each point (Note these two systems usually have less than 1 m difference and some GPS instruments will not operate GDA 94).
10. Around each sampling point 10 soil cores (approximately 20 mm in diameter) will be extracted to a depth of 10 cm from within a 10m radius of the centre of the sampling point. The location of each soil core will be random and can be located by the point marked by the tip of your boot (i.e. the point marked by every 5th step in the sampling point area). The step point method is a rapid method for locating random points within a quadrat. The method was as follows:
    a. Find the centre of the quadrat, and mark with a peg.
    b. Walk out 10 m in a randomly selected direction. Choose a point at the toe of boot. Take a 10 cm sample using the soil sampler.
    c. Select a second random direction and walk 5 m. Choose a point at the toe of boot.
    d. Take a 10 cm sample using the soil sampler. It is necessary to observe the centre of the quadrat and choose the random direction so that the sampling points remain within 10 m of the centre of the quadrat. This can be done effectively by moving around in a zig-zagging pattern in an anti-clockwise direction around the centre of the quadrat.
    e. Select further random points until 10 cores have been sampled within the quadrat.
11. Collection guidelines for the samples are:
    a. Carefully remove any surface litter and attached plant material from the soil surface before the core is taken.
    b. If the core is taken from the centre of a plant then remove as much plant material as possible
    c. Tilled seedbeds will require the following :
       i. If there has been full disturbance sowing with even seedbed and the soil is in a loose tilled condition, the depth of core should be increased to 0–11 cm. While it is better to

avoid sampling a tilled soil, this correction is based on the estimated settlement of a tilled seedbed under rainfall.

ii. If partially disturbed such as no till sowing the core should be taken from a surface which is equivalent to the original surface of the undisturbed seedbed. In some cases this may require taking the core from the point nearest to the tip of the boot where this can be obtained. Actual sowing rows should be avoided. To obtain the original soil surface it may be necessary to remove the “soil throw” from the sowing operation from the surface. This maybe a delicate operation but it should be relatively easy to identify the original soil surface.

12. Collect all soil samples in a bucket. Break up any clumps and mix as samples are collected from a station. Use a spatula or small garden shovel to mix the soil not hands.
13. Once all soil cores have been collected again thoroughly mix the soil in the bucket until the sample appears evenly mixed. Divide the soil sample between the two pre-labelled bags. Approximately 500g of soil will be sent for chemical analysis and the remaining soil retained for soil texturing. Note that good mixing of a bulked sample is a critical process. Poor mixing has a high probability of causing an erroneous or misleading result.
14. Take a photo from the centre of the point facing north, which focus on the soil surface within the station area.

A2 Associated lab analysis

Samples were analysed for C and N% (LECO), pH (water), texture, colour (Munsell), EC (1:5), Cations (ammonium acetate and KCl), P (Colwell), Phosphorus Buffer Index (PBI). The 0-10 cm C% can be used to predict the 0-30 cm C stock using Pedotransfer functions derived from the Cowra Trough soils. This measured C stock will indicate whether the site is appropriate for an Action-based contract, and provide an expected sequestration rate for the site.

Phase II - B. Initial sampling for outcome and hybrid based contracts

B1 Timing of sampling

To quantify soil carbon stock changes for an outcome based contract the sampling program has to be implemented at least twice (baseline assessment plus a measurement in the future). To account for temporal variability/changes, the sampling time and stage of crop/pasture development should be if possible the same. The recommended time is in February to April in the period after harvest and before the first tillage operation in cropping areas. The average and standard deviations obtained from the two or more samplings will be required to determine soil carbon stock change associated with a defined level of confidence.

B2 Field operations

1. Identify the target paddock or target area on a SPOT image or on an ADS40 air photo image if available. The image should be GIS compatible.
2. Identify details of differences in soil types and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type, differences in paddock history, and internal fences. Property maps provided by the producer and discussions with them and aerial photos can be valuable aids. A site visit can be used to assist with this mapping and identifying the important features of the paddock or target area.
3. Stratify the paddock and/or target area to be sampled. The target area may a single paddock or in some cases it will be a series of adjacent paddocks. The stratification can be based on factors such as:
    a. landform (crests, midslopes, footslopes, depressions)
    b. soil type
    c. rockiness and outcrops
    d. abundance of trees
    e. land management history if this is known to be different, as will often be the case with sites in which several paddocks are included or can sometimes within a single paddock e.g. stock camps, shade areas water points etc.
    f. any other factor likely to result in changes in soil type and changes in soil carbon levels.
4. Outline the areas identified as the stratification units on the GIS image (SPOT or AADS40).
    e. Determine how many of the 10 points are required within each stratified area. A suggested methodology is to assign points as a proportion of the area. If the area of the paddock or the site exceeds 100 ha then add 1 sample point per 10 ha.
    f. Each of the stratified areas is then divided into “n” equal areas where “n” is the number of random points to be sampled. Draw polygons around each of these equal areas.
    g. Select the function to choose random points within each polygon depicting the equal areas. Select a random point within each of the equal areas plus up to 2 extra points in case of rejection of sites for reasons outlined in Item 9. If the random points are too close to a fence or land on an obvious headland it is better to choose another random point using the GIS rather than spend expensive field time locating a point only to reject it.
    h. Record the coordinates of the random points selected by the GIS function in latitude and longitude. If Eastings and Northings are used, ensure note is taken of the projection in use so no errors occur when they are transferred to the paddock.
5. Locate points in paddock.

6. Examine each site to confirm it is the target soil type. Exclude points that have alluvial soils or depressions, basalt and very sandy soils (sandy loam or sandier). A hole may need to be dug to a depth 30-40 cm at 2 to 3 locations to confirm soil type.
7. Once a point has been confirmed, sketch a map of the paddock that details differences in soil types and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type and internal fences not already recorded. Property maps provided by the producer, and aerial photos accessed prior to the site visit can be used to assist with mapping. Map of previous stratification for sampling at the initial site visit will be provided by Lachlan CMA. This stratification may be retained or amended.
8. Determine the approximate area of any the different soils or paddock divisions and assign the appropriate number of sampling points to each to stratify the paddock.
9. Soil samples will be collected from 10 sampling points. The locations of each sampling station will be randomly allocated within the sampling group (e.g. soil groups or internal paddock). Sampling points will avoid the following:
   a. Headlands,
   b. Stock camps,
   c. Areas near trees (unless trees are a normal part of the area to be sampled)
   d. Any other areas showing obvious signs that they are an unusual part of the site.
10. A GPS reading will be taken from the centre of each point. The GPS unit needs to be set on either GDA 94 or WGS 84. (Note these two systems usually have less than 1 m difference and some GPS instruments will not operate GDA 94).
11. Around each sampling point 8 soil cores will be sampled to a depth of 30 cm from within a 20 m radius of the centre of the sampling station. Note that this will result is a quadrat of effectively 40 m being sampled. Sampling to 30 cm will also require extracting a core to a depth of 40 to 50 cm.
    a. The location of each soil core will be located using the following spiral procedure. These should be marked by pegs before bringing the coring machine onto the site. The most efficient passage of the coring machine should be planned to minimise traffic across the station.
       i. Reverse the vehicle with corer into northern end of the station
       iii. Measure 20m to the south to find the centre of the station and record GPS coordinates.
       iv. Use a pin to secure the end of the tape at the centre of the station.
       v. A total of 8 transects are then layed out, in N (00), NE (45°), E (90°), SE (135°), S (180°), SW (225°), W (270°), NW (315°) directions to mark 8 points in total to be sampled (Figure 3). Along each of these transects one point is selected at random from one of 10m, 15 m or 20 m from the centre of the plot.
       vi. Note the vehicle should be backed onto each of these transects to minimize traffic compaction along the transect.
    b. At the sampling of each the following procedure is followed:
       i. Remove any litter and attached plant material from the soil surface before the core is taken. If the core is taken from the centre of a plant then remove as much plant material as possible.
       ii. Settled seed bed /pasture surface condition – no special comments
       iii. Tilled seedbed, these should not be sampled. Sampling should only be done where it is possible to obtain settled seedbed conditions.

c. Each core is sampled in the following way:

  i. The hydraulic corer is used to sample the soil to at least 40 cm depth. The following guidelines apply to sampling to 40 cm:

    - The moisture of the soil is tested. Ideally the soil should be at the moderately moist state (see Table 2). A trial core should be done if there is any doubt about the suitability of the soil moisture content for sampling. When sampled the core should remain in an intact, coherent condition and show no or few signs of compaction or cracking. Particular care should be taken that the surface soil has not fractured resulting in small fragments of the surface soil contaminating the lower soil layers.
    - As a rule of thumb if the hammer part of the corer is required to be applied for more than 20 to 30 seconds, the soil is probably too dry to get good bulk density and soil carbon results throughout the full 30 cm core. Alternative sampling procedures need to be activated (see d).

  ii. The 40 cm soil core is removed from the steel core and placed on the tray designed to accept the core or the plastic PVC race (split PVC pipe). A gentle nudge from the wooden pole may sometimes be required to move the core especially in wetter conditions. The core should be treated carefully to ensure it remains in an intact, coherent condition.

  iii. The 50 cm steel rule is placed adjacent to the soil core and the length of the soil core recorded. At the same time the depth of the hole from which the core was extracted is recorded. These are compared. A note is made about whether soil has fallen into the hole. Ideally the depth of the hole ≈ length of the core. The tolerance is 1 to 2 cm. If the difference is greater than 2 cm, redo the core or go to 7d, Alternative Sampling Procedures.

  iv. The soil core is cut at the following intervals:

    - 0–10 cm
    - 10–20 cm
    - 20–30 cm

  v. For each point all the sample from each depth goes into a single bucket. It should be possible to place the bucket at the end of the tray of PVC race to collect the soil without any spillage. It is essential that no spillage occurs to obtain accurate bulk density information. The soil is mixed after adding the soil from each core.

d. Alternative Sampling Procedures

  i. If the surface can be sampled in an intact, coherent condition, but the subsoil is too hard and dry to sample without excessive hammering (more than 20 to 30 seconds) , it will be necessary to sample the surface soils separately. This can be done by sampling the 0-10 cm layer by hand using a 75 mm diameter core. The deeper layers can then be sampled using the hydraulic corer, as above.

  ii. If the whole soil profile is too dry to obtain an intact, coherent core, it will be necessary to wet the sites up. This requires the following procedure:

    - Select the sites where the cores are to be taken. This will usually mean only 5 cores per station will be taken. Insert the 150 mm PVC core into the soil to a depth of about 20mm. Fill the core with core with water (tank water or water with low salinity) to 100mm. Allow the soil to wet up.
    - As a rule of thumb, every 10 mm of infiltration will wet up 30 to 40 mm of soil. As the soil has to drain, usually it will be 24 to 48 hours before the moisture content of the soil is suitable to sample.

iii. If the difference between the length of the core and the depth of the hole is outside the 2 cm tolerance, then go to 7d(i). If this is unsatisfactory, it will be necessary to return to sample at another time when the soil moisture content is more suitable.

12. Once all soil cores have been collected, thoroughly mix the soil in the bucket and break up any clumps until the sample appears evenly mixed. Divide the soil sample between the two pre-labelled bags. Note that good mixing of a bulked sample is a critical process. Poor mixing has a high probability of causing an erroneous or misleading result.
    a. Note that best mixing is achieved by mixing the soil sample thoroughly each time after adding the soil from a core.
    b. Use a spatula or small garden shovel to mix the soil not the hands.
13. Take a photo from the centre of the point facing north, which focus on the soil surface within the station area.

B3 Associated lab analyses

A measurement of the dry soil bulk density is required at each sample location to allow organic carbon concentration data (%C) provided by an analytical laboratory to be converted into carbon stocks (Mg C/ha). This will require the following measurements to be made in the laboratory.

1. The wet weight of each sample (30 samples) will be weighed to 0.1 gms. The wet weight will include the weight of the bag so the weight of the bag needs to be known.
2. Three sub-sample of about 50 gms will be taken and oven dried to 105°C to determine the field moisture content. Before taking the sub-samples the bag of soil should be thoroughly mixed to ensure the soil has uniform moisture content. The sub-samples in the oven will be weighed until reach a constant weight (e.g. 48 hours). The weights for this determination will need to be weighed to 0.01 gm. The field moisture content is calculated using standard calculations as in the spreadsheet provided.
3. The individual soil samples will be air dried at 40°C. This will be 10 stations by 3 depths, 0–10 cm, 10–20 cm, and 20–30 cm.
4. The field texture will be determined on the soil.
5. The oven dry weight of soil for each sample will be determined from the field moisture content and the wet weight of the original sample. This will be done using the spreadsheet provided. The calculated oven dry weight along with the volume of the soil cores used to collect the samples in the field will then be used to calculate the bulk density of the soil.
6. Divide the air dried soil sample between two pre-labelled bags. One sample is to be sent away for further laboratory analysis (soil carbon, pH), the other to be kept as a reference.
7. The bulk density will be determined using the calculated oven dry weight of soil and the volume of soil, estimated from the core diameter used to sample the soil in the field
8. More detailed instructions for laboratory analyses will be provided after the sampling.

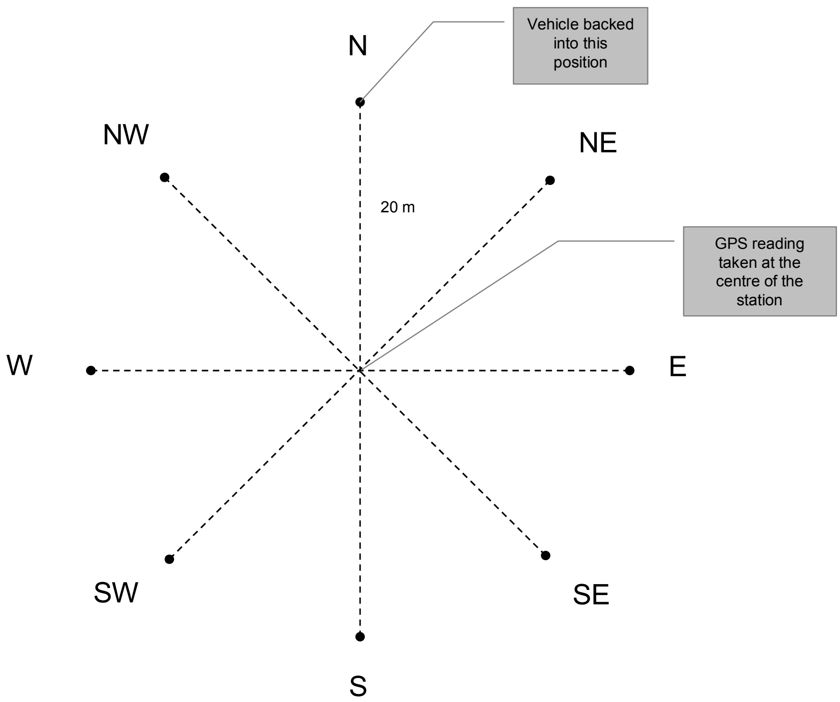
Further notes:

These procedures maybe done at the source location or at the analytical laboratory. Whether an individual laboratory performs this correction or not needs to be confirmed with the laboratory used.

1. The collected soil samples are to be air dried and sieved to <2mm with all material passing through the 2mm sieve being weighed and retained for subsequent carbon analysis. Note that the dry weight of any material >2mm (gravel content) needs to be recorded and applied as a correction factor in calculating the soil carbon stock.

2. The gravimetric water content of the air dried <2mm material must be determined and used to correct any carbon content data if this was not done by the analytical laboratory.
3. The gravimetric concentration of organic carbon (typically provided as %C) in the samples should be determined by sending the samples to an analytical laboratory accredited to perform this analysis. Ensure that samples containing carbonates are treated appropriately to provide a measurement of only organic carbon. A variety of accredited laboratories around Australia offer organic carbon analyses for soils.

Figure 2 Location soil cores are taken at each sampling station.



Phase II - C. Final sampling for outcome and hybrid based contracts

C1 Detailed sampling field operations

1. Resample at the 10 sample points used for the initial sampling in B.
2. At each sampling station 8 soil cores will be extracted to a depth of 30 cm from within a 20 m radius of the centre of the sampling station.
   a. The location of each soil core will be located using the following spiral procedure. These should be marked by pegs before bringing the coring machine onto the site. The most efficient passage of the coring machine should be planned to minimise traffic across the station.
      i. Locate the centre of the station from the GPS coordinates.
   b. Use a pin to secure the end of the tape at the centre of the station. Measure 20 m in a direction of 22.5° (NNE), 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5°, 337.5° to mark 8 points in total to be sampled (Figure 3). The return sites are offset to prevent resampling in the same location as at the initial sampling.). Along each of these transects one point is selected at random from one of 10m, 15 m or 20 m from the centre of the plot. At the sampling of each the following procedure is followed:
      i. Remove any litter and attached plant material from the soil surface before the core is taken. If the core is taken from the centre of a plant then remove as much plant material as possible.
      ii. Settled seed bed /pasture surface condition – no special comments
      iii. Tilled seedbed, these should not be sampled. Sampling should only be done where it is possible to obtain settled seedbed conditions.
   c. Each core is sampled in the following way:
      i. The hydraulic corer is used to sample the soil to at least 40 cm depth. The following guidelines apply to sampling to 40 cm:
         - The moisture of the soil is tested. Ideally the soil should be at the moderately moist state (see Table 2). A trial core should be done if there is any doubt about the suitability of the soil moisture content for sampling. When sampled the core should remain in an intact, coherent condition and show no or few signs of compaction or cracking. Particular care should be taken that the surface soil has not fractured resulting in small fragments of the surface soil contaminating the lower soil layers.
         - As a rule of thumb if the hammer part of the corer is required to be applied for than 20 to 30 seconds, the soil is probably too dry to get good bulk density and soil carbon results throughout the full 30 cm core. Alternative sampling procedures need to be activated (see d).
      ii. The 40 cm soil core is removed from the steel core and placed on the tray designed to accept the core or the plastic PVC race (split PVC pipe). A gentle nudge from the wooden pole may sometimes be required to move the core especially in wetter conditions. The core should be treated carefully to ensure it remains in an intact, coherent condition.
      iii. The 50 cm steel rule is placed adjacent to the soil core and the length of the soil core recorded. At the same time the depth of the hole from which the core was extracted is recorded. These are compared. A note is made about whether soil has fallen into the hole. Ideally the depth of the hole ≈ length of the core.

iv. The soil core is cut at the following intervals:
   - 0–10 cm
   - 10–20 cm
   - 20–30 cm

v. For each point all the sample from each depth goes into a single bucket. It should be possible to place the bucket at the end of the tray of PVC race to collect the soil without any spillage. It is essential that no spillage occurs to obtain accurate bulk density information. The soil is mixed after adding the soil from each core.

d. Alternative Sampling Procedures

i. If the surface can be sampled in an intact, coherent condition, but the subsoil is too hard and dry to sample without excessive hammering (more than 20 to 30 seconds) , it will be necessary to sample the surface soils separately. This can be done by sampling the 0–10 cm layer by hand using a 50 mm core. The deeper layers can then be sampled using the hydraulic corer, as above.

ii. If the whole soil profile is too dry to obtain an intact, coherent core, it will be necessary to wet the sites up. This requires the following procedure:

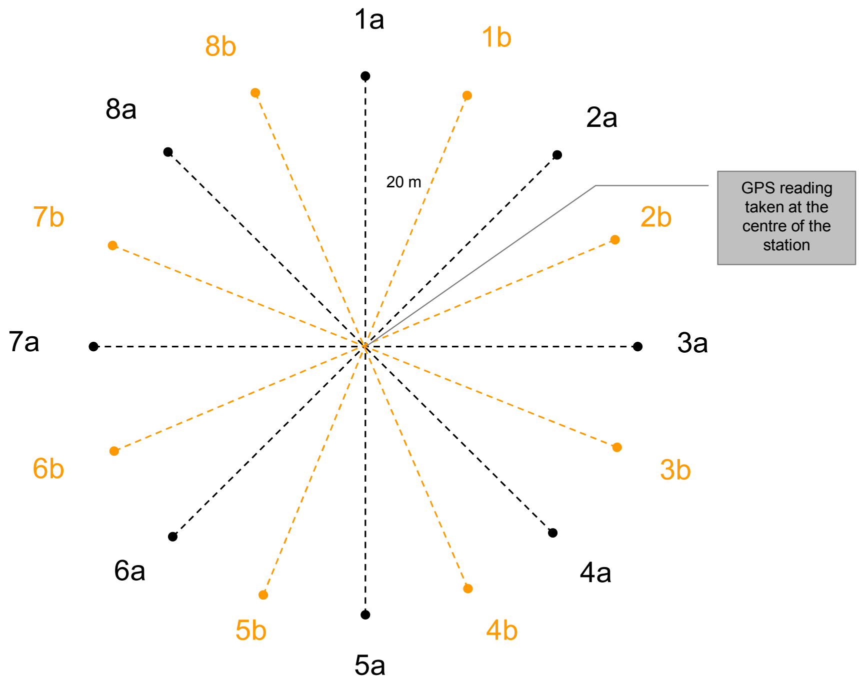
1. Select the sites where the cores are to be taken. This will usually mean only 5 cores per station will be taken. Insert the 150 mm PVC core into the soil to a depth of about 20mm. Fill the core with core with water (tank water or water with low salinity) to 100mm. Allow the soil to wet up over night.
2. As a rule of thumb, every 10 mm of infiltration will wet up 30 to 40 mm of soil. As the soil has to drain, usually it will be 24 to 48 hours before the soil is at a suitable moisture content to sample.

3. Once all soil cores have been collected, thoroughly mix the soil in the bucket and break up any clumps until the sample appears evenly mixed. Divide the soil sample between the two pre-labelled bags. Approximately 500g of soil will be sent for chemical analysis and the remaining soil retained as a reference. Note that good mixing of a bulked sample is a critical process. Poor mixing has a high probability of causing an erroneous or misleading result.
   a. Note that best mixing is achieved by mixing the soil sample thoroughly each time after adding the soil from a station.
   b. Use a spatula or small garden shovel to mix the soil not the hands.
4. Take a photo from the centre of the point facing north, which focus on the soil surface within the station area.

C2 Detailed sampling lab analyses

Same lab analysis as for Contract signing in B.

Figure 3 Location of the initial (a) and final (b) soil cores taken at each sampling point. The return sites are offset to prevent resampling in the same location.



C3 Audit procedure rationale

An accounting procedure to be used as a precaution to detect the possibility that the contractor has applied special land management practices on the quadrat sites being used to detect changes in soil carbon in the paddock. By measuring the soil carbon percentage the 0-10 cm layer on a set of newly selected random points across the paddock, this will indicate if the soil carbon levels on the standard quadrat sites used for estimating changes in soil carbon have an unusual level of soil carbon. An option is to check a given percentage of the Outcome based contracts and Hybrid contracts using this procedure. The cost will be minimal as only the 0-10 cm layer is measured for soil carbon and only the carbon percentage is measured, rather than the soil carbon store.

C4 Audit procedure field operations

1. This process will be carried out on a set of newly selected random points across the paddock.
2. Identify the potential points on the property. These are different stations to those used in Steps B and C.
3. Identify the target paddock or target area on a SPOT image or on an ADS40 air photo image if available. The image should be GIS compatible.
4. Identify details of differences in soil types and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type, differences in paddock history, and internal fences. Property maps provided by the producer and aerial photos can be valuable aids. A site visit can be used to assist with this mapping and identifying the important features of the paddock or target area.

5. Stratify the paddock and/or target area to be sampled. The target area may a single paddock or in some cases it will be a series of adjacent paddocks. The stratification can be based on factors such as:
    a. landform (crests, midslopes, footslopes, depressions)
    b. soil type
    c. rockiness and outcrop
    d. abundance of trees
    e. land management history if this is known to be different, as will often be the case with sites in which several paddocks are included or can sometimes within a single paddock
    f. any other factor likely to result in changes in soil type and changes in soil carbon levels.
6. Outline the areas identified as the stratification units on the GIS image (SPOT or AADS40).
    a. Determine how many of the 10 points are required within each stratified area assigned as a proportion of the area. If the area of the paddock or the site exceeds 100 ha then add 1 sample point per 10 ha.
    b. Each of the stratified areas is then divided into “n” equal areas where “n” is the number of random points to be sampled. Draw polygons around each of these equal areas.
    c. Select the function to choose random points within each polygon depicting the equal areas. Select a random point within each of the equal areas plus up to 2 extra points in case of rejection of sites for reasons outlined in Item 11. If the random points are too close to a fence or land on an obvious headland it is better to choose another random point using the GIS rather than spend expensive field time locating a point only to reject it.
    d. Select the function to choose random points within each polygon depicting the stratified areas. Select the number of points required plus 4 extra points in case of rejection of sites for reasons outlined in 5.
    e. Record the coordinates of the random points selected by the GIS function. These can be in latitude and longitude or Eastings and Northings but if the later are used ensure note is taken of the projection in use so no errors occur when they are transferred to the field.
7. Locate points in field.
8. Identify the potential stations on the property. These are different stations to those used in Steps A and B.
9. Sketch a map of the paddock that details differences in soil types and any major features e.g. creeks, dams, differences in landform, clumps of trees, areas of erosion, differences in soils/rock type and internal fences. Property maps provided by the producer, and aerial photos accessed prior to the site visit can be used to assist with mapping.
10. Determine the approximate area of any the different soils or paddock divisions and assign the appropriate number of sampling stations to each to stratify the paddock.
11. Soil samples will be collected from 10 sampling points. The locations of each sampling station will be randomly allocated within the sampling group (e.g. soil groups or internal paddock). Sampling stations will avoid the following:
    a. Headlands,
    b. Stock camps,
    c. Areas near trees (unless trees are a normal part of the area to be sampled)
    d. Any other areas showing obvious signs that they are an unusual part of the site.
12. A GPS reading will be taken from the centre of each station. The GPS unit needs to be set on either GDA 94 or WGS 84. (Note these two systems usually have less than 1 m difference and some GPS instruments will not operate GDA 94).

13. At each sampling station 10 soil cores (20 mm wide) will be extracted to a depth of 10 cm from within a 10 m radius of the centre of the sampling station.
14. The location of each soil core will be random and can be located by the point marked by the tip of your boot (i.e. the point marked by every 5th step in the sampling station area). Remove any litter and attached plant material from the soil surface before the core is taken. If the core is taken from the centre of a plant then remove as much plant material as possible.
15. The cores from each station will be bulked but kept separate. The samples from each station will be analysed separately.
16. Take a photo from the centre of the point facing north, which focus on the soil surface within the station area.

C5 Audit procedure lab analysis

The analysis will be for C% (LECO), pH (water), texture, colour (Munsell). The C% value for the 0-10 cm layer will be compared to the C% value from the Primary Sampling to test for consistency in the soil carbon values.

Definitions

Site – Contiguous area of a paddock or paddocks under the same land use that are being assessed for land use changes to store soil carbon.

Sampling point – The location within a site, where

1. For the initial sampling (initial site visit) to assess bids and for the Audit Procedure:
   a. A cluster where 10 cores are taken within a radius of 10 m.
   b. This effectively results in a 25 m quadrat.
2. For the hybrid/outcomes based contracts sampling at beginning and end of contract:
   a. A cluster where 8 cores are taken within a radius of 20 m.
   b. This effectively results in a 40 m quadrat.

Core – An individual soil core which is removed from the soil and cut into 0-10 cm, 10-20 cm and 20-30 cm layers for analysis.

Useful guidelines

Table 2 Estimating soil water status in the field (after McDonald et al. 1990)

Soil water status	Sands, sandy loams	Loams	Clay loams, clays
D – Dry	Will flow through fingers or fragments will powder.	Will not ball when squeezed in hand. Fragments will powder.	Will not ball when squeezed in hand. Fragments will break to smaller fragments or peds.
T – Moderately moist	Appears dry. Ball will not hold together.	Forms crumbly ball on squeezing in hand.	Will ball. Will not ribbon.
M – Moist	Forms weak ball but breaks easily.	Will ball. Will not ribbon.	Will ball. Will ribbon easily.
W – Wet	Ball leaves wet outline on hand when squeezed, or is wetter.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.

Guidelines:
Dry is below wilting point.
Moderately moist is the drier half of the available moisture range.
Moist is the wetter half of the available moisture range.
Wet is at, or exceeding, field capacity.

References

Allen, DE, Pringle, MJ, Page, KL and Dalal, RC (2010). A review of sampling designs for the measurement of soil organic carbon in Australian grazing lands. The Rangelands Journal 32, 227 – 246.

Bell, MJ and Worrall, F (2009). Estimating a region's soil organic carbon baseline: The undervalued role of land-management. Geoderma 152, 74 – 84.

Brus, DJ, Spätjens, LEEM and de Gruijter, JJ (1999). A sampling scheme for estimating the mean extractable phosphorus concentration of fields for environmental regulation, Geoderma 89, 129 - 148

Conant, RT and Paustian, K (2002). Spatial variability of soil organic carbon in grasslands: implications for detecting change at different scales. Environmental Pollution 116, S127 – S135.

DECCW 2009, Protocols for Soil Condition and Land Capability Monitoring, prepared by G Bowman, GA Chapman, BR Wilson, G Bowman, BW Murphy, BR Jenkins, T Koen, JM Gray, HB Milford and DT Morand, Department of Environment, Climate Change and Water NSW, Sydney.

Evans, RA and Love, RM (1957). The step-point method of sampling-a practical tool in range research. Journal of Range Management. 10(5):208-212.

Goidts, E, Van Wesemael, B, and Crucifix, M (2006). Magnitude and sources of uncertainties in soil organic carbon (SOC) stock assessments at various scales. European Journal of Soil Science 60, 723 – 739.

Hancock, GR, Murphy, D and Evans, KG (2010). Hillslope and catchment scale soil organic carbon concentration: An assessment of the role of geomorphology and soil erosion in an undisturbed environment. Geoderma 155, 36-45.

Lachlan CMA (2011) "Soil Carbon Pilot Project". Lachlan Catchment Management Authority, NSW Australia. http://www.lachlan.cma.nsw.gov.au/downloads/Soil_Carbon_Pilot/Fact_Sheets/Fact_Sheet_1_Soil_Carbon_Pilot_Overview.pdf

Lark, RM (2009). Estimating the regional mean status and change of soil properties: two distinct objectives for soil survey. European Journal of Soil Science 60, 748-756

McBratney, AB and Pringle, MJ (1999). Estimating average and proportional variograms of soil properties and their potential use in precision agriculture. Precision Agriculture 1. 125– 152.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990), Australian soil and land survey field handbook, Inkata Press, Melbourne.

McKenzie, N, Ryan, P, Fogarty, P and Wood, J (2000), Sampling, Measurement and Analytical Protocols for Carbon Estimation in Soil, Litter and Coarse Woody Debris. National Carbon Accounting System Technical Report No. 14, Australian Greenhouse Office, Canberra.

McKenzie, N, Henderson, B and McDonald, W (2002). Monitoring Soil Change. Principles and practices for Australian soil conditions. Technical Report 18/02. Land and Water, CSIRO. Australia.

Miklos, M, Short, MG, McBratney, AB and Minasny, B (2010). Mapping and comparing the distribution of soil carbon under cropping and grazing management practices in Narrabri, north-west NSW. Australian Journal of Soil Research 48, 248 – 257.

Sanderman, J, Baldock, J, Hawke, B, Macdonald, L, Massis-Puccini, A, and Szarvas, S (2011). National Soil Carbon Research Programme: field and laboratory methodologies. National Research Flagships, Sustainable Agriculture. CSIRO Land and Water, Waite Campus, Urrbrae SA 5064

Simbahan, GC, Dobermann, A, Goovaerts, P, Ping, J, and Haddix, ML (2006). Fine resolution mapping of soil carbon based on multivariate secondary data. Geoderma. 132, 471-489.

Singh, K, Murphy, BW and Marchant, BP (accepted). Towards cost-effective estimation of soil carbon stocks at the field-scale. Soil Research

Webster, R and Burgess, TM (1984). Sampling and bulking strategies for estimating soil properties in small regions. Journal of Soil Science 35, 127–140.

Wilson, BR, Barnes, P., Koen, TB, Ghosh, S and King, D (2010). Measurement and estimation of land-use effects on soil carbon and related properties for soil monitoring: a study on a basalt landscape of northern New South Wales, Australia. Australian Journal of Soil Research 48, 421–433.