



Verification Manual

for the

Assessment and Validation of Soil Carbon Reserves

Commitment to Quality

This manual forms part of the quality system of Prime Carbon. Prime Carbon partners with its suppliers and customers to provide products and services which support cooperative, sustainable environmental management and sustainable agriculture / land management.

Prime Carbon also provides services to carbon exchanges. The procedures described in this manual are designed to support statements about carbon accumulation in the soil of specified properties, resulting from specific management regimes.

We support the operations of carbon exchange mechanisms, and recognise their contribution to addressing important environmental issues. Prime Carbon customers who purchase carbon credits rely absolutely on the integrity of the information provided to them. They require the highest levels of confidence in the processes behind the information. It is essential that the processes which support statements about soil carbon status are followed carefully, to maintain and enhance the confidence that purchasers of carbon credits have in the process and the product.

Commitment to Continuous Improvement

If you identify any part of this manual which is not consistent with our quality objectives, with our current processes, or with the requirements and expectations of our customers, please contact the person responsible for maintaining our quality system. Their name is shown in Appendix 1.

With your support, we can make a difference to our common global future.

Ken Bellamy
Principal
Prime Carbon Pty Ltd

Principles of our Quality System

Our quality system is based on the international process standard ISO 9001, which requires that:

“The organization shall establish, document, implement and maintain a quality management system and continually improve its effectiveness in accordance with the requirements of this International Standard.

The organization shall:

- a) identify the processes needed for the quality management system and their application throughout the organization (see 1.2),
- b) determine the sequence and interaction of these processes,
- c) determine criteria and methods needed to ensure that both the operation and control of these processes are effective,
- d) ensure the availability of resources and information necessary to support the operation and monitoring of these processes,
- e) monitor, measure and analyze these processes, and
- f) implement actions necessary to achieve planned results and continual improvement of these processes.”

Background

When a land manager has made a commitment to the Prime Carbon Soil Enhancement and Carbon Sequestration (SECS) program, the increased carbon storage on the subject property must be validated.

Under the terms of our Agreement, the land manager must supply:

- The Lot and Real Property (RP) descriptions of the subject property(ies),
- A sketched map of the blocks on the property to participate in the program, on a print from a moderate resolution satellite image,
- A list of those blocks to participate in the program,
- History of land use (crop history or if grazing, watering sites and known cattle camps),
- Terms and conditions of entry,
- Other administrative documents.

Overview of Process

The Data Manager has responsibility for assessing the available data, acquiring supplementary data, and ensuring that the soil carbon status report is produced for the property.

Once agreement is reached with the Land Manager, or on annual reviews, the validation survey takes this format:

- Desktop Survey: collation of relevant soil information documents,
- Selection of the validation system most suited to the subject property,
- Consultation with Land Manager regarding timing and any access issues,
- Confirmation of the subject areas,
- Instructions to data capture providers,
- Data capture,
- Collation and secure storage of raw data,
- Instructions to data analyst soil organic carbon modeller,
- Recording of decisions about model generation for future review of processes,
- Preparation of report including table of zones with baseline and elevated soil organic carbon status for each zone,
- Review of process and results.

Selection of Validation Processes for Initial Soil Carbon Survey

The Data Manager has three options in validation processes. These are not exclusive, but taken together form the toolkit with which the Data Manager may develop an informed view based on high confidence about the soil organic carbon status.

The tools include:

- Geo-referenced soil sampling regimes in combination with geo-statistical mapping of the data,
- High resolution aerial imagery and/or hyperspectral data for the site,
- Geo-statistical modelling using datasets from multiple sources including the combination of limited laboratory soil sampling to validate hyperspectral data.

The selection between these options will exercise the skill of the Data Manager. Levels of sampling high enough for geo-statistical analysis alone may engage costs that are out of proportion. There is no single approach that is suitable in every case, except to assess each situation on its merits, and record the rationale for the decision.

Baseline Data is Necessary to Demonstrating Improved Soil Carbon Levels

If there is no history of soil carbon status in the form of soil sample testing results (that meet the standard), there are two options:

1. a baseline is established by paired sites of same soil type, and no treatment/management to enhance soil carbon, or

2. a baseline is established at entry into the program on the subject land. Improved soil carbon levels are assessed after changed management practices are implemented.

For paired sites to be selected there must be evidence that the land use is very similar on the baseline site as on the treated site, and there is strong similarity in existing vegetation, land forms and geology.

For example, cane lands within the same soil type, having the same land use history and similar position in the landscape (and hence subject to the same flooding events for example), would make suitable paired sites. There must be higher resolution soils mapping that would identify fundamental soil types and their distribution on the subject property.

Where no paired sites are available for establishing a comparison, the soil physical sampling may be carried out on a set of sites or sectors per property.

Geo-Referenced Soil Sampling Regimes in Combination with Geo-statistical Mapping

As McKenzie, N et al. note in *Sampling, Measurement and Analytical Protocols for Carbon Estimation in Soil, Litter and Coarse Woody Debris*: "Short-range spatial variation of soil properties is usually substantial."

For this reason, a minimum of four samples is required per given site of:

- soil type,
- location within landscape/parent material where there is variation in the subject site,
- land use history.

Select sites by inspecting the property information. This should be done using a geographic information system (GIS) and taking note of the historical use map, soil maps, satellite image, property boundaries (DCDB) and contours.

The Data Manager must develop a matrix of the items above taking note to utilise several landscape locations if the terrain is undulating.

Every effort should be taken to establish the soil types on the subject property. Some properties will have little or no variation in soil types; others will have considerable variation within short distances.

The following table provides minimum soil sampling regimes for sites where no soil map is available. These will be rare circumstances. A property is one contiguous holding, and may be composed of several titles.

Property Size	Minimum Sectors of Sampling
Up to 300 ha	4 sectors of 10 x 10 m
Between 301 and 1000 ha	6 sectors of 10 x 10 m
Between 1001 and 2500 ha	10 sectors of 10 x 10 m
Between 2501 and 5000 ha	12 sectors of 10 x 10 m
More than 5000 ha	15 sectors of 10 x 10 m

Sites on which to locate sectors should be carefully selected to match the criteria below as well:

- Sites should incorporate management history proportionally. If the property is entirely cropped except for areas of native forest, or drainage lines for example, the impact of management is minor. If however, some areas are not cropped, and are used for grazing, then the sampling sites should be distributed proportionally to the amount of land given to each activity.

For example, if on a 500 ha property 250 ha are cropped, and 125 ha are grazed, the sampling sites would be 4 sites in cropping and 2 in grazing.

Once this distribution is made, then the sites within management zones (in this case cropping and grazing are separate zones) should be located to incorporate soil types proportionally.

- Sites should capture soil type variation where the area of the variation would cause an impact on the overall result. Small areas of variation can be safely excluded from sampling.

For example, there may be two fundamental soil types within the cropping zone and only one in the grazing. The cropping sector sites would be further divided into two sites within each soil type.

- Sector sites should be established at locations where the geology of the farm does not heavily influence the outcome. For example, sites should not be established at the tops of hills, nor at the foot of the slope. Mid slope is preferred. In addition, sites should not be established close to creeks or in flooded areas unless this characteristic is widespread on the property.

Data Manager to Specify Data Acquisition Requirements

The Data Manager, having assessed the data acquisition requirements for the site, will provide the specifications to the Land Manager or directly to a recommended supplier as may be appropriate.

The Land Manager will chose among the recommended providers listed at Appendix 2 should they elect to facilitate the data collection process.

Single Composite Samples

Where the audit process requires only a single composite sample to establish a single value across the farm, the above principles should be adhered to in establishing sector sites.

The soil samples should be weighed before mixing and each sample should be modified to a single weight that is used in each case. For example, the samples may be each adjusted to weigh 250 gm. Samples should also be mixed thoroughly for 5 minutes in a clean container such as a large drum. It is important that mixing not introduce contamination from other uses to which the mixer may have been used. It is not appropriate for example to use a cement mixer that has been used for mixing concrete or grout, since it will introduce lime into the soil.

Once mixing is complete, remove a single soil sample from the aggregated mixture, and forward it to the laboratory.

Preparation for the Field Visit by the Soil Sampling Provider

Sketch the sites on separate layer and print table of positions. Export the sites layer to the project CF card for use in a suitable GPS unit.

Export table of sites, and create unique bar codes for each sample site, adding a unique code to every table row in a column added for this purpose.

As the unique codes can be printed using a bar code font, print out the codes using a laser printer to avoid the risk that labels will smear and become unreadable. The label should include the property name, site position in WGS 84 and the bar code unique to this sample. Attach the sample labels to sample plastic bags. Sample bags should be zip lock bags of sufficient size to hold half a litre of soil.

If a rugged hand held computer with GPS is not used, print out the map of the property with the sample sector sites shown on the map, along with the name of the property and other necessary identifying features.

Forward by fax to the Land Manager: the plan to conduct sampling including date of visit, the name of the Soil Sampling Provider, contact details of Prime Carbon, and the table showing locations of samples. In many cases it may be a requirement of the land manager that the Soil Sampling Provider use transportation provided on site, and not drive a vehicle into the property beyond a shed or gate. This is often prompted by a concern about the introduction of pests or diseases especially soil-borne diseases.

Tools required on site include:

- The soil sample coring device,
- Two clean dry buckets with tight fitting lids: one for bulking soil samples, and one to hold samples in the field,
- The sample bags,
- The GPS device or ruggedized computer with GPS,
- Indelible ink pen for writing on/signing sample bag.

Prior to departure ensure that the GPS is configured to use either the geographic coordinate system GDA94 or WGS 84. WGS 84 is commonly used in GPS units. Record which system is being used.

Proceed to the first site. This can be done by local knowledge supplemented by the GPS or ruggedized computer which can show either the present coordinates or on a different page, the required track to the selected site. Some GPS units, and all ruggedized computers can also show the aerial image of the location of the site in a moving map format.

Select the appropriate sample bag to store the results. This bag should be clearly labelled by name and by the coordinates of the location. If using the ruggedized computer/TDS Nomad, scan the sample bag bar code. Confirm that the location of the sample is correct from the menu.

Individual sample sites must be a square with sides of 10 metres in length. For most individuals, a big stretching pace is a metre.

Clear away the surface debris and vegetation prior to taking the sample.

Sampling should be carried out on a T shaped pattern within the selected site. Seven sample cores should be taken to a depth of 150 mm. These should be distributed in the following way:

- Three cores should be taken from the top of the T,
- Two cores should be taken from the leg of the T,
- One core should be taken from each side of the leg of the T .

Place each sample in the sample mixing bucket. One of the parameters being tested is soil moisture. Do not allow rain to contaminate the soil sample. The date of the last known rain for the site should be recorded, especially if this is within the last five days.

Once all seven soil cores are placed in the mixing bucket, stir the soil cores together for not less than 60 seconds.

Remove 250 grams or about half a litre of soil from the bulked sample and place in the soil sample bag, and seal it carefully. Write your initials on the label with the indelible ink pen.

Provide any explanatory notes on why the sample may vary from the specification. Examples of variations include the inability to get to the sample site, the inability to get seven samples as required, etc. The reasons explaining the variance are required to enable review of the sampling procedures and/or SECS Agreement.

As soil moisture is an important characteristic of the soil sample, ensure that soil samples are not left in exposed conditions during transit. Close and seal the sample bag carefully.

Record a GPS waypoint in the centre of the sampling sector. Only one GPS waypoint is required for each seven samples/sector site. The GPS log of waypoints should be forwarded to Prime Carbon with the other documentation. In addition, the Form: Soil Sample Record, found at Appendix 3 should be completed on the site and forwarded to Prime Carbon as well.

On return to the office, fold the top of the bag once, and staple all bags with two staples to prevent them opening by accident.

Soil samples must be sent promptly to selected laboratories for testing. Send samples by courier or deliver in person. A list of recommended NATA-approved laboratories is provided at Appendix 2. Prime Carbon uses SGS Australia laboratories.

Complete the SGS Chain of Custody consignment sheet specifying that soil samples should be analysed for:

- Total Carbon (TC),
- Total Organic Carbon (TOC),
- Total Moisture,
- Soil Type/Soil Structure,
- Total Available Phosphorous by Colwell methodology

Place the Chain of Custody consignment sheet in the package containing the soil samples.

Send the soil samples to the SGS laboratory selected, by courier at the earliest possible convenience so that samples are not affected by storage.

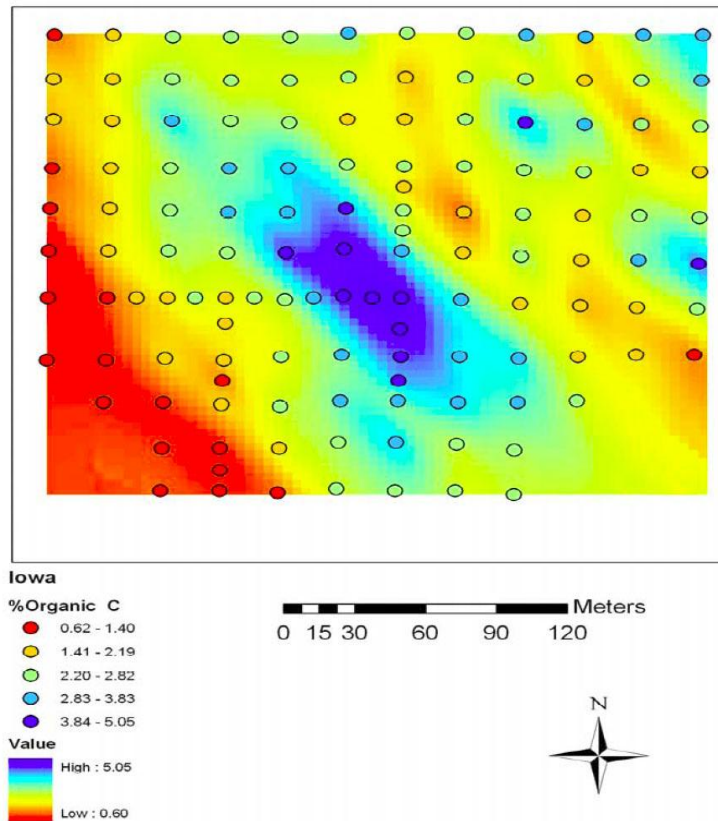
When the samples have been analysed and the data is available

Ensure that the sample information is clearly and unequivocally identified. The barcode numerical representation enables you to confirm that the results being entered are for the appropriate sample bag. That is to say that the barcode will be shown as a series of numbers in the database record, which allows the operator to confirm that the sample results are recorded against the correct sample number.

It is preferable to enter the results into the sample database by copying and pasting.

The sample results are now available for quantification of soil organic carbon in the areas subject to the agreement. The data should be supplied to the Geo-statistics operator, who will produce Kriged maps from the sample data.

A final report should be prepared showing a table of zones and mean sample values for soil organic carbon.



A Kriged map. *Venteris, E. and Slater, no date.*

Aerial High Resolution plus Hyperspectral Imaging

The well recognised spatially variable nature of soils places high requirements on soil sampling/analysis regimes when the modelling strategy is geo-statistical projections as kriged maps.

Imagery can supplement this strategy by sampling on a grid pattern of variable size from the air. Imagery ground sample distance can vary from squares of less than 150 mm length to more than 250 metres on a side, depending on the sensor used. Smaller ground sample distances are typical of aerial sensors, while the larger ones are typical of satellite sensors. The suitability of any ground sample distance/sensor is dependent on the scale of the assessment being undertaken. Pixels/GSD of 250 m may be suited to landscape scale analysis, while pixels of less than 500 mm GSD may enable soil measures within horticultural enterprises. Vital Resource Management Pty Ltd (VRM) is providing tools for carbon assessment at farm or enterprise level.

It is also widely recognised that Soil Organic Carbon (SOC) can be measured using spectrometers (Stephens S.C. et al. and Ben-Dor et al.2006), and hence imaging spectrometers are considered to be an optimal choice for the acquisition of a large number of SOC measures. Imaging spectrometers are also known as hyperspectral imaging devices. They may be carried on satellites or on aerial platforms, and are limited in their resolution. GSD is often large.

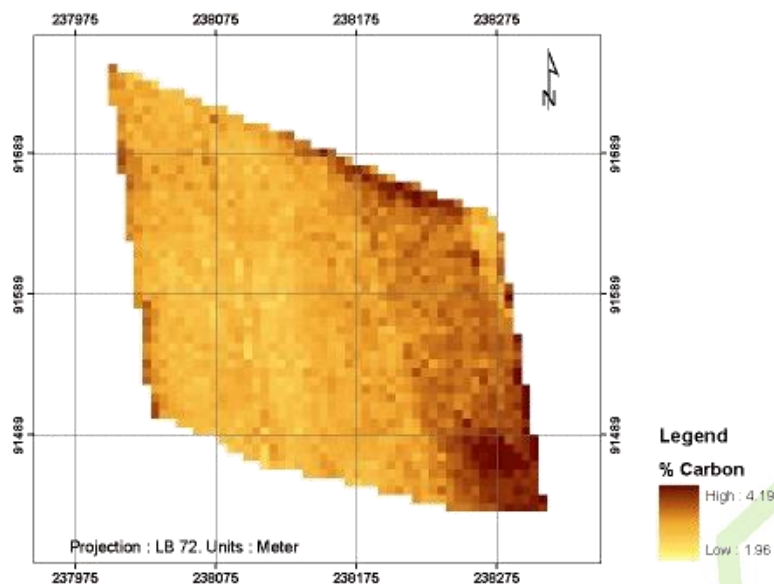
Hyperspectral imaging devices capture parts of the electromagnetic spectrum in narrow slices. These narrow slices make up an image cube. The extent of the electromagnetic spectrum that is captured by a given sensor varies. Many of the sensors are limited to below 1000 nm; others can reach to the upper levels of the short wave infrared domain at 2800 nm.

Hyperspectral imaging devices are not readily available, but where aerial hyperspectral devices can be cost effectively hired, they enable a strategy which gives high confidence for specific sites at specific times. The device must be capable of capturing two slices: 2220 nm and 2270 nm. This allows an analyst to process the data to provide a map where the Carbon Difference Index of Stephens et al is used.

CDI= 2220nm – 2270 nm.

Some satellite data is available that will also provide useful data. Stephens S.C. et al suggest that Aster Band 6 and Band 7 are well aligned with the spectral slices noted above. Therefore CDI= Aster Band 6 – Band 7.

See also Stevens A. 2005. *Detection of carbon stock change in agricultural soils with VIS-NIR-SWIR spectroscopy and airborne-hyperspectral remote sensing.*



Critically, for this strategy, soil must be visible from above, and not significantly obscured by vegetation cover. Remote sensing algorithms enable the assessment of the presence or absence of materials within pixels. This is to say that by using hyperspectral imagery, it is possible to detect the presence of a material such as SOC even when the soil is not cultivated, for example in grazing lands under significant grazing pressure. There are also times in the crop cycle in cropped lands where the soil is visible. Soil must also not be saturated with water, as the water will dominate the reflectance from the surface.

It is also necessary to use high resolution true colour imagery to assist in the interpretation of the hyperspectral data. True colour imagery is readily and intuitively understood. It provides more detailed representation in shapes of the surface features, due to its higher resolution in ground sample distance.

There may be instances where true colour imagery is the optimal choice given other limitations. Soil organic matter is often correlated with soil colour. The data is used to develop soil zones for physical sampling.

The Data Manager must therefore select between these options with the aim of achieving the optimal confidence level in SOC assessment. Aster satellite data may be the optimal choice for extensive areas under grazing for example. In this case it is prudent to validate the image analysts results using point data from on site soil sampling. This sampling would be at much greater distance than when conducted as the sole source of validation data.

Where airborne hyperspectral and high resolution true colour data are chosen, the Data Manager must determine through conversations with the Land Manager of the subject property, and through understanding of the farming system in place, the degree to which soil is visible on the surface.

The Data Manager must specify to the image supply contractor the details of the subject property.

The list of specifications provided must include:

- The shapefile of the subject area on the property, and the cadastral boundaries.
- The scale/ground sample distance of the imagery required. This will be optimised between the GSD of the true colour camera, the GSD of the hyperspectral imaging device and the limits set by the plane.
- Written specifications setting out that image capture cannot be conducted when the soil surface is saturated with water should be forwarded to the aerial capture operators, and specifying the hyperspectral bands that are required – two narrow bands centred on 2220 nm and 2270 nm.

The Data Manager must also specify that:

- Where image mosaics are to be created, radiometric qualities of the true colour data are to be preserved if they are to be used in subsequent image analysis.
- If the purpose of the RGB data is the production of a high resolution image or transect image, then the colour balancing that is typical of photogrammetric software is acceptable.
- The data must be supplied with the metadata including flight log from the system. This will specify the date and time of capture as well as some other parameters for each image.
- Data supply should include the true colour image originals, often in .raw format or another proprietary format for a given camera.
- The log file of the image analysis (from ENVI, ERDAS Imagine or other remote sensing package) should be attached to the analysis results from the hyperspectral data, to inform quality systems.
- The results of the analysis be provided as a geo-referenced image in .tiff format. WGS 84 is the preferred projection, but GDA94 is also acceptable.

Data Storage

Data is organised in the geo-database. Client records by property must have a folder within them for the storage of original data. Name subdirectories of this folder by date of capture. Data stored within these original data folders should not be modified. Copies of original data can be modified by analysis but must be renamed.

It is desirable but not always feasible, to have on site validation by a field spectrometer. The ASD Field Spectrometer is suitable for the task, as its sensitivity reaches the required wavelengths. Where soils are measured on site, the GPS location must be recorded. Strategies for sampling site determination should match those used to establish sampling sites whether for physical analysis in specified laboratories or by on site hyperspectral analysis. If sites have already been established for the subject property, all or part of these should be used.

The geo-database is the subject of a separate quality/operational manual.

Soil Organic Carbon Mapping using Data from Multiple Sources

Although much research is directed at identifying a single remote sensing strategy for the accurate assessment of soil organic carbon, present knowledge suggests that in many cases one or another limitation will point the auditor in the direction of a mixed strategy.

This multi-variate approach uses modelling and draws on the range of information available from a variety of sources and measures to develop a map of soil carbon on which reliance can be placed.

The analysis of soil carbon in this scenario is carried out in a geographic information systems (GIS) environment such as ArcGIS with Geostatistical Analyst, Spatial Analyst and 3D Spatial Analyst.

The data types that are utilised by the modelling approach include sources of varying authority. The Data Manager should indicate to the analyst the level of confidence he/she has in the accuracy of data sources where these rely on memory. Such data includes historical land use for example. This type of information is valuable for its temporal accuracy and some inaccuracy in the spatial domain is acceptable. The land owner may know that cane was grown on some parts of the farm in years past but not be certain of its extents within a metre, for example. Cultivation oxidises soil carbon.

Information sources which the Data Manager should provide to the analyst include:

- A digital terrain model at a scale appropriate to the subject property,
- Soil classification maps in digital form,
- A shapefile showing historical land use where available,
- A base image with sufficient resolution/GSD to allow recognition of surface features that are important at the scale appropriate to the subject property,
- The results of hyperspectral imaging and subsequent analysis,
- Results of all laboratory soil testing with the GPS locations of the samples.

As before, these must all be supplied in a single projection, preferably WGS 84.

The analyst should be asked to:

- Develop stratifications in which elevation and separately, slope are tested for correlation with soil organic carbon as measured by either hyperspectral or laboratory analysis results. Where there is significant correlation, SOC zones should be developed on a separate layer.
- Develop zone maps as above using the soil classification in correlation with either hyperspectral or laboratory analysis results. Where there is significant correlation, SOC zones should be developed on a separate layer.
- Examine any correlation between previous land use and present SOC.
- Develop and document a robust model of soil organic carbon which provides high confidence about mapped soil carbon layers.

Final Report

The final report should include notes on the process of assessment, and a table listing the zones in the subject property, with the area listed and the mean soil organic carbon value for that zone.

Appendix 1

Quality Manager

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Appendix 2

List of Preferred Service Providers

Image Providers

Agrecon
170 Haydon Drive
Bruce ACT 2617
Phone +61 (02) 6201 2552
www.agrecon.canberra.edu.au

School of Surveying & Spatial Information Systems
Faculty of Engineering
University of New South Wales
Sydney NSW 2052

E.R.I.C

Land and Water Management

Soil Sampling Providers

Soil Analysis Laboratories

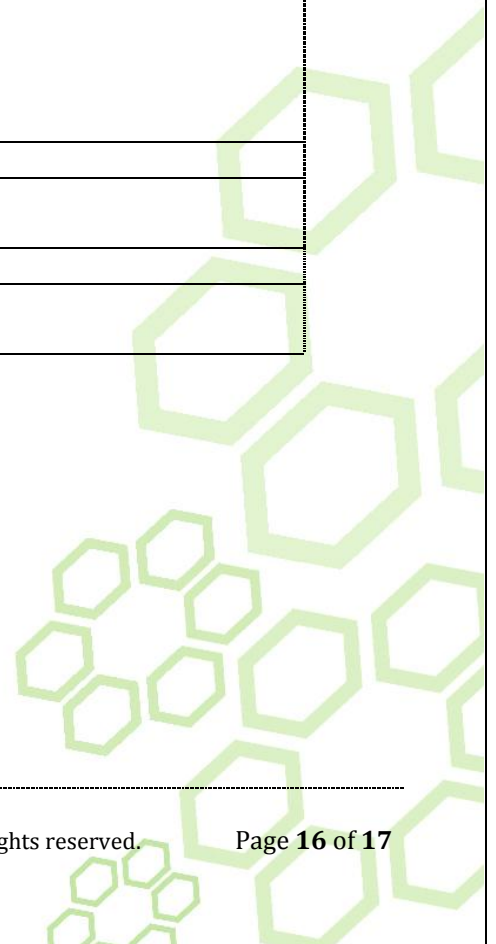
SGS (various locations; please see a listing at <http://www.au.sgs.com/>)

Charles Sturt University – Soil Laboratory

Appendix 3

Form: Soil Sampling Report (Minimum Data)

Property or Owners Name	
Nearest Town	
State	
Sample Location on Map	
GPS Coordinates	
Date of Sampling	
Time of Sampling	
Notes	
Name of Sample Collector	
Signature	



References

Ben-Dor, E., R.G. Taylor, J. Hill, J. AM Dematte, M.L. Whiting, S Chabrilat, and S. Sommer. 2006 *Imaging Spectroscopy for Soil Applications*. IGARSS, Denver.

McKenzie, Neil; P. Ryan; P. Fogarty; and J. Wood. 2000. *Sampling, Measurement and Analytical Protocols for Carbon Estimation in Soil, Litter and Coarse Woody Debris*. Australian Greenhouse Office.

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Stevens, A. 2005. *Detection of carbon stock change in agricultural soils with VIS-NIR-SWIR spectroscopy and airborne-hyperspectral remote sensing*.

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From <http://geospatial.osu.edu/conference/proceedings/ppts/venteris.pdf>