A Protocol for Monitoring Soil Condition and Soil Health in North Central Victoria

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NORTH CENTRAL
Catchment Management Authority
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Australian Government

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This report was prepared by RM Consulting Group for the North Central CMA.

Photos:
Front cover – Cropping on granitic sands at Dunluce, soil pit at Lockington
Inside cover – Direct drill cropping on alluvial plains at Serpentine

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Executive Summary

This study has recommended practical indicators and measuring methods to assess and monitor the condition and health of soils in the North Central region over time. Suitable sampling protocols and monitoring regimes have been recommended to ensure comparable results over time. It will be essential to collect repeated measurements at the same site over a long period of time. The differences between the individual samples taken can then be analysed to detect relatively small changes, some of which will only become detectable over extended periods, probably decades.

The review has considered the most important soil condition or health issues for each of the main soil types and land uses in the region. These are loss of organic carbon and soil biota, soil structure decline, soil loss through erosion, nutrient imbalances, soil acidification, and salinity and sodicity.

Total organic carbon is the foundational indicator of soil condition. The levels of organic carbon are directly linked to the physical structure and chemical properties of the soil and are a signal of the soil's overall fertility and health. Organic carbon levels have a marked influence on soil colour, aeration, nutrient status, and water holding properties. Total organic carbon is a standard part of soil sample analyses.

Suitable indicators of specific chemical properties of soils that are related to soil salinity and sodicity, soil pH and nutrient status have also been selected. Similarly two physical properties, aggregate stability and penetration resistance, have been selected to monitor changes in soil structure. Finally, two indicators of soil erosion risk, groundcover and soil texture, have been identified, as well as a direct measure of soil loss.

The review recommends that these measurements be conducted on ten soil monitoring sites that are representative of the main soil types where soil condition issues and agricultural production is most prominent in the region. The feasibility of establishing reference farms to host monitoring sites should be investigated. An effective way to store, display and share soil condition information would be through a web based interactive mapper. This type of system provides the perfect platform to view changes in soil health over time and space. Data will need to be stored in a manner that will maintain its integrity in the long term. There are currently a number of these programs up and running. For this project it may be possible to add data to one of the pre-existing systems, or to use these programs as a stepping stone to develop a new independent system specific to meet the needs of the North Central CMA.

Changes in soil condition are difficult to monitor because they can occur irregularly and progress very slowly over a long time. The indicators proposed will provide robust information on four indicators of the health of the region's soils – soil organic matter, soil chemistry, soil structure and erosion risk.

As specific purposes for monitoring are better defined (relevant at the regional and/or local level), some or all of these indicators could be monitored depending on the level of resourcing available. Increasing the organic carbon content of regional soils is a goal that has clear benefits, including better structure, increased yields, and carbon storage to mitigate against climate change. It may, however, be more cost effective to monitor the main drivers of soil condition change, such as land management practices, rather than soil condition directly. Similarly, modelling approaches to better understand the relationships between soil condition and land management will also be helpful.

PART A REVIEW OF SOIL CONDITION INDICATORS AND LOCAL SOILS ISSUES

1 Introduction

1.1 Project background

The project aims to develop practical indicators and measuring methods to assess and monitor the condition and health of regional soils over time. These will need to be easily and cost effectively adopted. The project is seeking information on a systematic and quantifiable approach where soils data can be geo-referenced and all information products become readily accessible to interested parties in the North Central community.

1.2 Methodology

The approach taken has involved a review of relevant literature and discussions with relevant soil scientists and practitioners involved in developing and executing soil health monitoring projects in agricultural systems across other parts of Australia.

1.3 Outputs

The main output from this project is a report considering the range of methods that could be deployed to quantitatively monitor the condition and health status of local soils in the North Central region over time. The focus will be on agricultural soils. Another output includes a summary of existing soil data bases (national) and soil monitoring methods.

1.4 Soil health status (or measured condition)

Soil health status describes the actual (measured) condition of the soil in relation to its potential capacity to sustain flora and fauna, promote plant and animal health and maintain environmental quality (potential or target condition, Figure 1-1).

Soil condition is the result of complex interactions between many soil properties, all of which are determined by environmental factors (e.g. climate, topography), inherent soil properties (e.g. soil type, texture) as well as land use type and management practices (on a farm and landscape scale). Understanding the soil health status is critical for the ongoing management of Australia's natural assets and agricultural sustainability. The soil health status determines a soils capacity to fulfil soil functions.

Major soil functions:

- Habitat for living organisms on and in soils
- Carbon, nutrient and water cycling
- Decontaminating and filtering of harmful substances
- Basis for agricultural production.

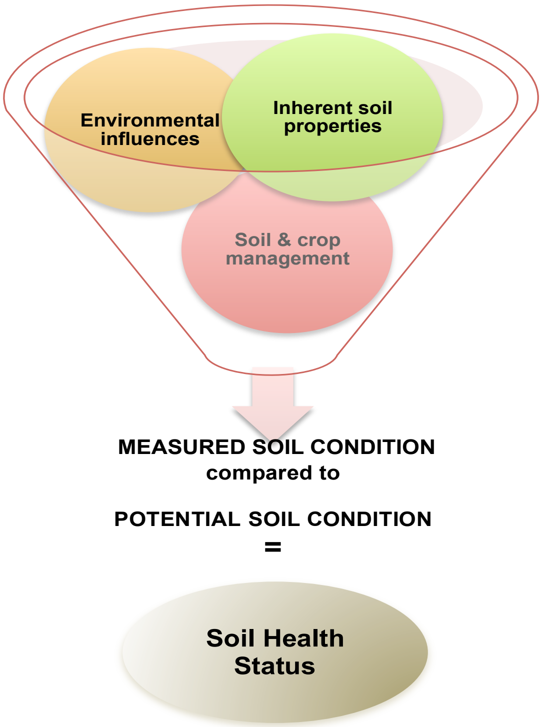

Figure 1-1: Determining the soil health status

For the purposes of this study, the term ‘soil heath’ refers to the soil health status.

Agricultural soils

The condition of soils used for agriculture drives production and environmental sustainability in a productive landscape. To some extent, agricultural soils have been changed from their natural status to make them suitable for production. Major actions include choice of production system, liming, tillage, fertilising, pest, disease and weed control and irrigation. The extent to which these management practices are applied and balanced determine soil condition. The overall management of productive landscapes (e.g. by catchment) also affects soil condition.

Soils in poor condition provide diminished sustainability. The major issues affecting the condition and function of agricultural soils are:

- Loss of organic carbon
- Loss of and or changes in soil fauna and flora
- Soil structure decline / compaction
- Soil loss / erosion
- Reduced water storage and use efficiency
- Reduced nutrient storage and use efficiency / nutrient imbalances
- Salinity / sodicity
- Acidification

Given the need to describe the status of productive soils and changes over time, the above issues will guide our selection of soil health indicators and quantitative monitoring tools.

2 Soil condition monitoring - an Australia wide update

A summary of current soil information and monitoring programs follows:

1. National Soil Condition Monitoring Program (NSCMP)

This program was commissioned by the Australian Government through its Caring for our Country (CfoC) initiative in 2011. CfoC is investing in the uptake of land management practices by farmers which will slow and reverse rates of soil acidification and increase soil organic matter. Resource condition monitoring is needed to establish whether these investments are helping to improve soil condition. Given that changes in soil pH and soil carbon can occur quite slowly, a long term program which monitors sites every 5 years will be needed for these changes to be detected.

National objectives:
The National Soil Condition Monitoring Program is designed around three questions:

1. What are the magnitudes and directions of soil organic carbon and soil pH changes for representative soil and land use combinations?
2. What are the levels of certainty (statistical confidence) associated with the measured soil carbon and pH changes?
3. What can be inferred about the changes in soil carbon and pH across different environments and the influence of land use and/or land management? Is Australia's soil resource degrading, maintaining or improving under current agricultural systems?

See link:

http://www.daff.gov.au/natural-resources/soils/national-soil-condition-monitoring

Victorian NSCMP objectives

1. Create quality controlled soil data for use in measuring and modelling agricultural production from Victorian soils and impacts of farming systems on soil health by 2014.
2. Achieve a better understanding, of the interactions between farming systems and soil health, through quantitative and qualitative analysis of available data by 2014.
3. Enable next users to access quality controlled soil information to use in modelling, mapping and decision making by 2014.

Of particular note:
The Victorian component of the National Soil Condition Monitoring Program is being managed by DEPI and there is four years monitoring data available from four sites covering the Central Victorian southern slopes and Wimmera plains, focusing on soil acidification and soil carbon monitoring. The final outputs of the project are to be delivered by June 2014.

Victorian contact:
Dr Richard MacEwan
Department of Primary Industries and Environment
Future Farming Systems Research Division, Epsom, Victoria.

2. The Soil Carbon Research Program: assessing soil carbon across Australia (SCaRP)

Project summary:
The SCaRP has been the largest and most extensive soil sampling and analysis program undertaken in Australia to measure stocks of soil carbon. The SCaRP has analysed more than 20,000 samples from a wide range of soil types and farming operations across more than 4000 different locations. A consistent method for sampling and a rapid and cost-effective way of analysing the content and composition of soil organic carbon has been developed.

See link:

http://www.csiro.au/Organisation-Structure/Flagships/Sustainable-Agriculture-Flagship/Soil-Carbon-Research-Program.aspx

Of particular note:
The project has developed a new simple, fast and inexpensive technique for measuring carbon in soils.

See link:

http://www.csiro.au/en/Outcomes/Climate/Understanding/Measuring-Carbon-In-Soils.aspx

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3. National Soil Quality Monitoring Program

Project summary:
The objectives of the National Soil Quality program is to:

1. Establish benchmarked sites to identify and highlight the nature and extent of soil biological, chemical and physical constraints to production systems.
2. Provide the basis of an ongoing soil quality monitoring and education program.
3. Examine soil properties (biological, chemical and physical) through Australia's agricultural regions.
4. Enable farmers and other land managers to compare their soil test results amongst their catchments and regions.
5. Identify positive and negative changes in soil quality over time with the overriding goal of developing better farming systems.

See link:

http://www.soilquality.org.au

Of particular note:
Victoria has not uploaded soil information into the database as of 13 August 2014.

Victorian contact:
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4. Soil and Landscape Grid of Australia

Project summary:
The Terrestrial Ecosystem Research Network (TERN) is scheduled to release the Soil and Landscape Grid of Australia around mid 2014. This will include national scale soil maps, new terrain surfaces and online systems to estimate model parameters.

See link:

http://www.tern.org.au/Soil-and-Landscape-Grid-of-Australia-pg17731.html

5. National Soil RD&E Strategy

The federal Minister for Agriculture, the Hon Barnaby Joyce formally launched this strategy in March 2014. The strategy:

- Provides an overview of soil RD&E in Australia, including challenges and drivers for soil RD&E.
- Considers current investment and capability in soil RD&E.
- Presents a future RD&E plan, including goals and strategic directions.
- Considers roles and responsibilities and co-investment.
- Provides a set of implementation actions.

See link:

http://www.daff.gov.au/natural-resources/soils/national_soil_rd_and_e_strategy

Contact information:
Strategy secretariat Tel 02 6272 3933
For regular updates on the implementation of the national soil RD&E strategy send an email to soilsRDE@daff.gov.au with ‘subscribe’ in the subject line.

6. Australian Soil Resource Information System (ASRIS)

Project summary:
ASRIS provides online access to the best publicly available information on soil and land resources in a consistent format across Australia. It provides information at seven different scales.

- The upper-three scales provide general descriptions of soil types, landforms and regolith across the continent.

- The lower scales provide more detailed information in regions where mapping is complete. Information relates to soil depth, water storage, permeability, fertility, carbon and erodibility. Most soil information is recorded at five depths.
- The lowest scale consists of a soil profile database with fully characterised sites that are known to be representative of significant areas and environments.

Sponsors:
ASRIS is a product of the Australian Collaborative Land Evaluation Program. Funds have been provided by CSIRO Land and Water and the Department of Agriculture. Collaborating state and territory agencies provide substantial in-kind resources and technical support.

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Relevance of national soil monitoring programs to this project

The Victorian component of the National Soil Condition Monitoring Program is being managed by DEPI and there is four years monitoring data available from four sites covering the Central Victorian southern slopes (seasonal horticulture/potatoes – Ferrosol soils) and Wimmera plains (broadacre cropping of cereals and pulses – Vertosol soils). Sampling has been undertaken at 1 – 40 cm (at 10 cm intervals) focusing on soil acidification and soil carbon monitoring (specifically measuring EC, pH, bulk density and organic carbon content). The final outputs of the current project are to be delivered by June 2014.

The main difference between the National Soil Condition Monitoring Program and SCaRP is to do with the temporal aspects of soil sample collection. SCaRP will provide an assessment of current soil carbon status and what the integrative effect of land use history has been on soil carbon levels. It is intended that the National Soil Condition Monitoring Program will initiate and monitor change through time using repeated sampling on a 5 year return basis and thus establish the ongoing impact of land use and management practices.

The objectives of the National Soil Quality program are very similar to the objectives of this North Central CMA project, however, it is being delivered on a national rather than regional scale i.e. to establish benchmarked sites to identify the nature and extent of soil biological, chemical and physical constraints to production systems, provide the basis of an ongoing soil quality monitoring and education program, enable farmers and other land managers to compare their soil test results amongst their catchments and regions, and identify positive and negative changes in soil quality over time with the overriding goal of developing better farming systems. The Soil Quality program data base is very user friendly, however, it would appear that the Victorian component of the project including soil data has not been uploaded into the database as of August 2014.

3 Indicators of soil health

Soil condition indicators providing information about soil health status can be divided into three broad categories:

- Biological indicators or 'life' – for example, soil flora and fauna, organic matter.
- Chemical indicators or 'materials and their properties': for example, organic matter, minerals (nutrients), acidity or alkalinity (pH), electrical conductivity (EC), contaminants, cation exchange capacity (CEC).
- Physical indicators or 'construction' – soil texture and structure determining; for example, aggregate stability, pore sizes and distribution (permeability and water holding capacity), bulk density, organic matter levels.

3.1 Biological properties

Soil biology plays a vital role in determining many soil characteristics. The decomposition of organic matter by soil organisms has a major influence on soil fertility, plant growth, soil structure, and carbon storage. Soil life, soil biota, soil fauna, or edaphon are collective terms for all organisms within a soil profile, or at the soil-litter interface. These organisms include earthworms, nematodes, protozoa, fungi, bacteria and different arthropods.

Biological properties are dynamic; they change over time as well as with management; they can respond quickly to changes in the environment and management (more so than physical or chemical indicators)

- *There is little evidence that directly links biological indicators to productivity (or risk) but good evidence linking biological indicators and soil properties or processes (such as cation exchange, water holding capacity, nutrient cycling ..)*[1]

Organic matter can be used as a reasonable stable indicator for biological soil properties i.e. all the materials that are <u>or were</u> associated with living organisms. It is hard to measure in its complexity so total organic carbon (TOC, by combustion) is measured instead i.e. % C provided as part of a conventional soil analysis by most laboratories. TOC is routinely measured to make soil management decisions.

Bardgett, R.D., 2005, The Biology of Soil: A Community and Ecosystem Approach, Oxford University Press
Coleman D.C. et al., 2004, Fundamentals of Soil Ecology, 2nd edition, Academic Press
Coyne, 1999, Soil Microbiology: An Exploratory Approach, Delmar
Doran, J.W., D.C. Coleman, D.F. Bezdicek and B.A. Stewart. 1994. Defining soil quality for a sustainable environment. Soil Science Society of America Special Publication Number 35, ASA, Madison Wis.
Paul, P.A. and F.E. Clark. 1996, Soil Microbiology and Biochemistry, 2nd edition, Academic Press
Richards, 1987, The Microbiology of Terrestrial Ecosystems, Longman Scientific & Technical
Sylvia et al., 1998, Principles and Applications of Soil Microbiology, Prentice Hall
Soil and Water Conservation Society, 2000, Soil Biology Primer.
Tate, 2000, Soil Microbiology, 2nd edition, John Wiley
van Elsas et al., 1997, Modern Soil Microbiology, Marcel Dekker
Wood, 1995, Environmental Soil Biology, 2nd edition, Blackie A & P

3.2 Chemical properties

The weathering of the parent material by water determines, to a large extent, the chemical composition of the soil. Some elements are leached into the lower soil layers where they accumulate. Less soluble ones are left in the upper layers of the soil. Chemical properties of soil are mineral composition (nutrients), organic matter content, pH, EC, CEC and potentially contaminants.

Chemical properties are a combination of inherent and dynamic properties and change over time and with environmental conditions and land management

- *Chemical properties can promote or constrain plant growth and soil biology, and thus affect crop growth/yield and natural plant communities. They can be measured by conventional soil tests and directly linked to ecology and agricultural productivity.*

Chemical properties measured usually include nutrient levels and fertility indicators such as, but not limited to, cation exchange capacity pH, EC, TOC. Desirable ranges exist for chemical indicators for different soils (textures / types), environments and crops. They are used to make soil management decisions[2].

3.3 Physical properties

The physical properties of soils, in order of importance, are texture, structure, bulk density, porosity, consistency, colour and resistivity (soil strength). Most of these determine the aeration of the soil and the ability of water to infiltrate and to be held in the soil. Temperature can also be considered a physical property.

Indicators of the physical status of soils measure inherent characteristics of the soil and those that can be changed by soil management

- *Texture and colour are inherent, derived from the soil's parent material and cannot be readily influenced by land management; these properties are usually determined as part of a conventional soil test; they have a marked influence on other soil properties*

- *Structure and related indicators (bulk density, porosity, aggregate stability) can, to some extent, be changed by land management and have a major impact on plant growth and soil biology (e.g. via access of plant roots to air, water and nutrients) and therefore soil condition; still, these indicators are not routinely measured to make management decisions.*

3.3.1 Texture

Soil texture as an inherent soil property affects many physical and some chemical indicators (e.g. organic matter, pH). This will in turn influence soil biology and plant growth. Table 3-1 provides a guide on the impact of soil texture on some soil properties.

[2] Khan T.O., 213; Soils, Principles, Properties and Management. ISBN: 978-94-007-5662-5 (Print) 978-94-007-5663-2 (Online)

Table 3-1 Generalised influence of soil texture on some properties / behaviour of soils[3]

Property / behaviour	Sand	Silt	Clay
Water holding capacity	Low	Medium to high	High
Aeration	Good	Medium	Poor
Drainage / infiltration rate	High	Slow to medium	Very slow
Natural soil organic matter level / sequestration potential	Low	Medium to high	High to medium
Decomposition of organic matter	Rapid	Medium	Slow
Warm-up	Rapid	Moderate	Slow
Compactability	Low	Medium	High
Susceptibility to wind erosion	Moderate (High if fine sand)	High	Low
Susceptibility to water erosion	Low (unless fine sand)	High	Low if well aggregated, otherwise high
Shrink /swell potential	Very Low	Low	Moderate to very high
Sealing of ponds, dams, and landfills	Poor	Poor	Good
Suitability for tillage after rain	Good	Medium	Poor unless well aggregated and stable
Pollutant leaching potential	High	Medium	Low (unless cracked)
Ability to store plant nutrients	Poor	Medium to High	High
Resistance to pH change	Low	Medium	High

3.3.2 Soil structure

Soil structure affects aeration, water movement, heat transmission, plant root growth and resistance to erosion. Water has the strongest effect on soil structure due to its solution and precipitation of minerals and its effect on plant growth and soil life. Plant growth and soil fauna and flora in turn affect soil structure.

Soil structure often gives clues to its texture, organic matter content, biological activity, past soil evolution, human use, and the chemical and mineralogical conditions under which the soil formed. While texture is defined by the mineral component of a soil and is an inherent property of the soil that does not change with agricultural activities, soil structure can be improved or destroyed by the choice and timing of farming practices.

Aggregation

‘Clumping’ of the soil textural components (sand, silt and clay) with iron oxides, carbonates, clays, and silica, organic matter and soil biology forms aggregates. The further association of those aggregates into larger soil structure units is called peds. Aggregates have distinct geometric forms depending on soil chemistry, biology and natural expansion-contraction,

[3] Nyle C. Brady & Ray R. Weil (2009). Elements of the Nature and Properties of Soils (3rd Edition). Prentice Hall. ISBN 9780135014332.

freezing-thawing, and wetting-drying cycles. Mechanical disturbance e.g. via tillage or traffic can destroy aggregates resulting in compacted layers or soil clods. Clods are not aggregates or peds. They indicate structural degradation, usually due to land management.

Aggregates (and clods) are a measure of soil structure – shape, surfaces texture, stability

Dispersion and slaking

Dispersion and slaking are indicators of the stability or instability of aggregates and thus soil structure.

- Slaking indicates the stability of soil aggregates and their resistance to erosion. The level of slaking suggests how well soil can maintain its structure to provide water and air for plants and soil biota when it is rapidly wetted. Limited slaking suggests that organic matter is present in soil to help bind soil particles and micro-aggregates into larger, stable aggregates. High slaking describes a condition where soils slake into very small fragments and run together when wet and set hard when dry; forming a crust that inhibits seedling emergence.
- Dispersion indicates aggregate stability and is correlated with the amount of sodium on exchange sites, and is influenced by calcium and organic matter levels. Dispersive soils have a very unstable structure and can form a surface crust or hard clods when dry. Pores below the surface can become blocked as the particles disperse. They are likely to swell significantly when wet which restricts water and air movement. A tendency to slake or disperse indicates poor aeration, water storage and drainage. The dispersiveness of a soil determines its likely response to calcium.

3.3.3 Bulk density, porosity and pore size distribution

Bulk density (BD) describes the weight of soil in a given volume. BD in conjunction with porosity (the fraction of the total soil volume taken up by pore space) and pore size distribution is a measure of soil structure. These indicators allow determining the extent of compaction. Compacted soil of certain mineral and organic matter content has a higher BD than soil that is not compacted. Compacted soil of certain mineral and organic matter content has less large and medium size pores and more small, poorly draining pores than soil that is not compacted. Compacted soil has poor aeration; it dries and wets more quickly than soil that is not compacted i.e. infiltration, water holding capacity and drainage will be poor.

BD, porosity and pore size distribution are closely correlated. Like other structure indicators, they give information about soil permeability for air and water movement and a soil's suitability for root growth and thus nutrient and water exploration. Many natural and management processes can influence porosity, pore size distribution and thus BD (Table 3-2).

Table 3-2: Possible effects of routine soil processes on pore size distribution.

Mechanical compression
• can decrease the size of macropores
• can close macropores
• can break up aggregates, reducing the number of intra-aggregate pores and thereby reducing the fraction of the pore space represented by the smallest pores
Disturbance from digging or ploughing
• can destroy existing macropores
• can create macropores between clods
• can break up aggregates, reducing the number of intra-aggregate pores and therefore also the fraction of the pore space represented by the smallest pores
Biological activity
• can create new macropores
• can enlarge macropores, as by ongoing traffic of ants or burrowing mammals
• can decrease the size of macropores, for example if they are affected by compression resulting from the expansion of a nearby root
• can increase aggregation, promoting the creation of inter-aggregate macropores, and possibly to smaller inter-granular pores within aggregates
• can constrict or obstruct pores, for example by growth of microorganisms
Chemical activity
• can constrict or obstruct pores by formation of precipitates
• can enlarge pores by dissolution of precipitates
• can increase or decrease inter-particle cohesion, with complex effects on pore size and structure
Shrinkage
• can enlarge macropores
• can create new macropores
• (within an aggregate) can cause intra-aggregate pores to decrease in size, or to increase in size if clay particles are shrinking
Swelling
• can decrease the size of macropores
• can close macropores
• (within an aggregate) can cause intra-aggregate pores to increase in size, or to decrease in size if clay particles are expanding

Aggregate stability is one factor that reduces the impacts of soil processes on pores.

4 Soil sustainability issues in the North Central region

4.1 Regional overview

Soil sustainability issues in the North Central region arise from a combination of soil attributes (parent material, their chemistry and biological properties), climate and seasons, and land management practices. The North Central region was severely affected by drought and below average growing season rainfall between 1997 and 2009 with resulting poor crop yields, poor stubble cover over summer months and increased grazing pressure on limited groundcover. The 'millennium' drought was followed by 2 years of higher than average rainfall. Locust plagues were seen in the plains area during sowing time in 2010 with extensive spraying and re-sowing required. Particularly damaging high summer rainfall led to extended periods of flooding in each of the local river systems (Campaspe, Loddon, Avoca and Avon-Richardson) between September 2010 and March 2011. Mice plagues, summer weed problems, heavy stubbles and flood damage affected the following 2011 sowing season. Harvest yields have been up and down since the millennium drought with tough finishes (or dry springs) experienced over the past few seasons.

In this section, the main soil sustainability issues for the North Central region are described.

4.2 Soils, geology and land use

Plains soils and geology

The dominant geomorphology or landform in the northern part of the region is the Riverine Plain comprised of marine plains (gravels, sands, clays and silts) overlain by the alluvial sediments of the various river floodplains. The plains comprise unconsolidated sediments of Tertiary and Quaternary age.

Red duplex soils with bleached A2 horizons and neutral to alkaline sub soils dominate the alluvial plains. Their subsoils are sodic and their surface texture ranges from sandy loam to clay loam over a medium to heavy clay (Sodosols). The extensive plains areas also support gilgaied clays or Vertosols. Agricultural production can be limited by poor penetration of moisture and inherently high sodicity and salinity. The major soils in the drainage depressions areas include sodic, grey texture contrast soils (grey Sodosols) and cracking clay soils (or Vertosols). These soils have slightly acidic sandy clay loam surfaces over grey light clays that increase in sodicity with depth. To the north west of the region are the Calcarosols which comprise dark brown to red-brown sandy loam, to clay loams overlying a clay sub soil (commonly known as "Mallee soils" or red brown earths). These occur on the undulating plains or the higher level alluvial plain[4].

<u>Land use</u>

The main dryland land use is mixed farming comprising predominantly cereal cropping, and grazing sheep for wool production and prime lambs, with some beef cattle. The predominant land use in irrigated areas is dairying, lucerne for grazing and hay production and some cropping for grain. Rainfall is winter dominant and ranges from less than 400 mm in the north west up to 500 mm in the south eastern part of the Riverine Plain.

[4] Victorian Resources online, Department of Primary Industries. St Arnaud 1:250000 & Swan Hill 1:250000 Geological Surveys, Department of Natural Resources and Environment; A study of the land in the Campaspe catchment, CF&L 1987.

Highlands soils and geology

The highlands have a great diversity of soil types that reflect differences in parent material, topography, climate, organic activity and age or degree of weathering. There are five broad landform and geology types that support soils with a range of capabilities and susceptibility to land degradation. These geological units comprise alluvial plains, sedimentary and granite rises, metamorphosed sediments, and volcanic plains and hills. The dominant landforms in the highlands are Ordovician sandstone and mudstone forming the hill country and Quaternary alluvium in the flood plain areas[5].

The Ordovician hill country supports shallow stony gradational soils comprising clay loams with low soil water capacity. Moving from the upper to lower slopes, the soils become sandier transitioning to sandy clay loams/sandy loams in the mid slope areas to fine sandy loams on the floodplain alluvium. Agricultural production can be limited by poor penetration of moisture and inherently high sodicity and sometimes salinity. There are high salt stores in these landscapes contributing to a high amount of soluble salts entering streams. Soils in the alluvium can be moderately well drained and support good farm production. The soils on the sedimentary slopes (Kurosols) have a strong texture contrast between the top soils and sub soils and tend to exhibit poorer drainage and dispersible clay subsoils of an acidic nature (high aluminium, magnesium and sometimes sodium). Dermosol soils can be present in the steep hill country and these have stonier profiles and can be excessively drained[6].

<u>Land use</u>

The main land use is mixed farming comprising predominantly sheep grazing for both wool and prime lamb production. Cropping programs in the sedimentary and granite areas tend to focus on growing supplementary feed for livestock and renovating pasture paddocks. Noting that both sedimentary and granitic derived soils tend to have clayey and acidic sub soils which can make pasture improvement using perennials difficult. In the volcanic hills (supporting Ferrosols soils) in the southern/central highlands there is more beef production and some vegetable growing, including potatoes. Rainfall is winter dominant and ranges from around 500 mm along the fringe of the highlands increasing to over 1000 mm in the highest altitude areas in the south of the catchment.

4.3 Soil deterioration and soil loss

4.3.1 Erosion

Soil structure, organic matter content and erosion risk are linked; poorly structured soil with low organic matter content is more prone to erosion than well structured soil. Apart from these variable indicators, inherent factors like **soil texture, slope length and steepness** (exposure), and farmer decisions on **land use and land management** determine erosion risk. The other management related indicator that can add to or reduce erosion risk is **soil cover percentage**. Exposed soil of and under the same conditions erodes more easily than covered soil, especially if covered soil is held together by extensive roots systems (e.g. pasture). Exposure to wind, heavy rain and or flood increases erosion risks. Soil texture impacts are shown in the earlier Table 3-1: Generalised influence of soil texture on some properties / behaviour of soils.

[5] SCA (1982) A study of the Land in the Catchment of the Avoca River; Schoknecht (1988) Land Inventory of the Loddon Catchment.
[6] The Australian Soil Classification, CSIRO.

Land use affects susceptibility to soil erosion

Highly susceptible land uses include:

- Fallow without stubble
- Broad acre crops without stubble retention
- Prepared ground for pasture re-sowing
- Livestock while soil cover is poor
- Grazing of forage crops / poor pastures during dry or wet conditions
- Potatoes and most vegetables

On high risk sites, these land uses should be avoided.

Less susceptible land uses include:

- No-till cropping systems
- Permanent pasture with good soil cover
- Perennial crops (fruit, vines) with use of mulch
- Native vegetation

Related deterioration processes due to land management

Soil biology

Loss / lack of replenishment of organic matter due to extensive tillage, erosion, drought (lack of growth), pesticide use and associated changes in soil fauna and flora.

Soil Chemistry

Acidification, nutrient losses or imbalances, salinisation, sodicity and associated deterioration in soil structure, reduced nutrient holding capacity (can be due to loss of or changes in the composition of organic matter).

Soil Physics

Soil structure decline, especially compaction due to tillage, traffic, loss of organic carbon, pugging by livestock.

Regional issues

The extensive Riverine plain or alluvial soils can be degraded by compaction and surface sealing, particularly on the duplex soils, where frequently cultivated. Wind erosion is also a problem where there are sandy loam topsoils exposed without groundcover. The most prominent problems with the red Sodosols are their hard setting surfaces and all these soils tend to have high sodicity in the subsoil. Improving the structure of the red sodic cropping soils is a high priority for farmers. On the other hand, the Calcarosols to the north west are relatively productive under agriculture presenting as medium-textured soils with favourable structure, water retention and fertility.

The plains soils are prone to wind erosion when left unprotected by crop residues or stubbles, or have insufficient ground cover in grazed paddocks. The millennium drought meant that poor performing crops left light stubbles and there was increased grazing pressure on reduced ground cover. However, the rapid move to no-till cropping systems and a marked reduction in sheep numbers across the region has substantially reduced the erosion risk on the plains.

The soils on the hill slopes are prone to sheet and gully erosion, especially where there are soils with hard setting surfaces and low levels of groundcover. Grazing pressure needs to be carefully managed in cleared hill country to prevent soil erosion. High runoff rates in the steeper hill country can lead to gully erosion, even in forest areas. Gullying can still occur on cropped sedimentary rises and weathered granitic sands in the mid catchment areas where cultivated and ground cover is poor. These soils will often have mottled and bleached sub soils indicating poor drainage and they can be hard setting due to their sodicity (high sodium and low calcium levels). Lower metamorphic rises are also susceptible. Granitic sands (or yellow duplex soils) are also especially prone to wind erosion when groundcover is inadequate. Salinity occurs where water tables are raised at the break of slope and in drainage depressions causing saline discharge areas, saline soils and increased salinity in surface waters.

4.4 Sodic soils

Sodicity occurs where there is a significant proportion of sodium in soil compared with other cations and this interferes with the soil's structural stability, causing hardpans, surface crusting and ponding of rainfall at the surface. Under sodic conditions clay soils may swell and clay particles will disperse or separate from aggregates, blocking soil pores, and resulting in poor soil structure. Upon drying these soils will tend to set hard and be cloddy. The addition of calcium and/or organic matter can reduce the constraints on production posed by sodic soils[7].

The red sodic cropping soils (or Sodosols) on the northern plains tend to have hard setting surfaces and high sodicity in the subsoil. These soils have slightly acidic sandy clay loam surfaces over light clays that increase in sodicity with depth. Sodicity is also a problem in the soils of the sedimentary hills and rises, as described in the regional issues section above.

4.5 Salinity development potential

Shallow saline watertables (less than 2 metres from the surface) can cause salts to accumulate in the plant root zone through capillary action, bringing salts to the surface and affecting plant growth, causing saline soils and loss in production. There are also production losses due to the lesser known about 'transient salinity' where there is accumulation of salts in the root zone without the influence of rising saline groundwater[8].

Groundwater and salinity issues in the North central region

Broadly there are regional groundwater systems beneath the highland valleys and plains, and local flow systems within the bedrock or hill country.

Localised groundwater flows in fractured rock aquifers within sandstone bedrock is mostly confined to sub catchment divides and discharges at the break of slope and in valley floors

[7] Kelly and Rengasamy (2006). Diagnosis and Management of Soil Constraints. University of Adelaide, GRDC
[8] Kelly and Rengasamy (2006).

causing dryland salinity. Larger and fresher groundwater aquifers are evident in the basaltic hills and valley systems. By contrast, groundwater flow is very shallow in granite landscapes moving between the weathered material above the hard underlying granite rock, discharging as springs and into drainage depressions causing local salting[9].

Following the wet period in the early 1970s groundwater monitoring indicated sustained rising water tables throughout the upper and mid catchment areas and marked increases in saline discharge areas. Since the millennium drought, however, water tables have stabilised and the risk of further salinisation in these catchments has reduced.

The two major regional groundwater systems on the plains are the shallow Shepparton Formation overlying the deeper Calivil/Renmark or deep lead aquifer.

Similarly, during the 1980s and 90s the vast majority of the northern plains irrigation districts had groundwater levels less than 2 meres below the surface. There was a dramatic shrinking in the area of high water tables during the extended drought period (1997 to 2009). This can be attributed to a combination of improved irrigation management practice, reduced winter/spring rainfall (or drought) and less irrigation water being applied. Although the urgency for further action on groundwater and salinity control has reduced soil salinity remains an important issue in the North Central region.

[9] Loddon Catchment Salinity Management Plan, Loddon Community Working Group.

5 What to measure?

A review of current literature and consideration of local soil sustainability issues has informed the development of an approach to monitoring the condition and health of regional soils over time. Figure 5-1 outlines a rationale for matching soil condition indicators with land management threats and other constraints on soil condition.

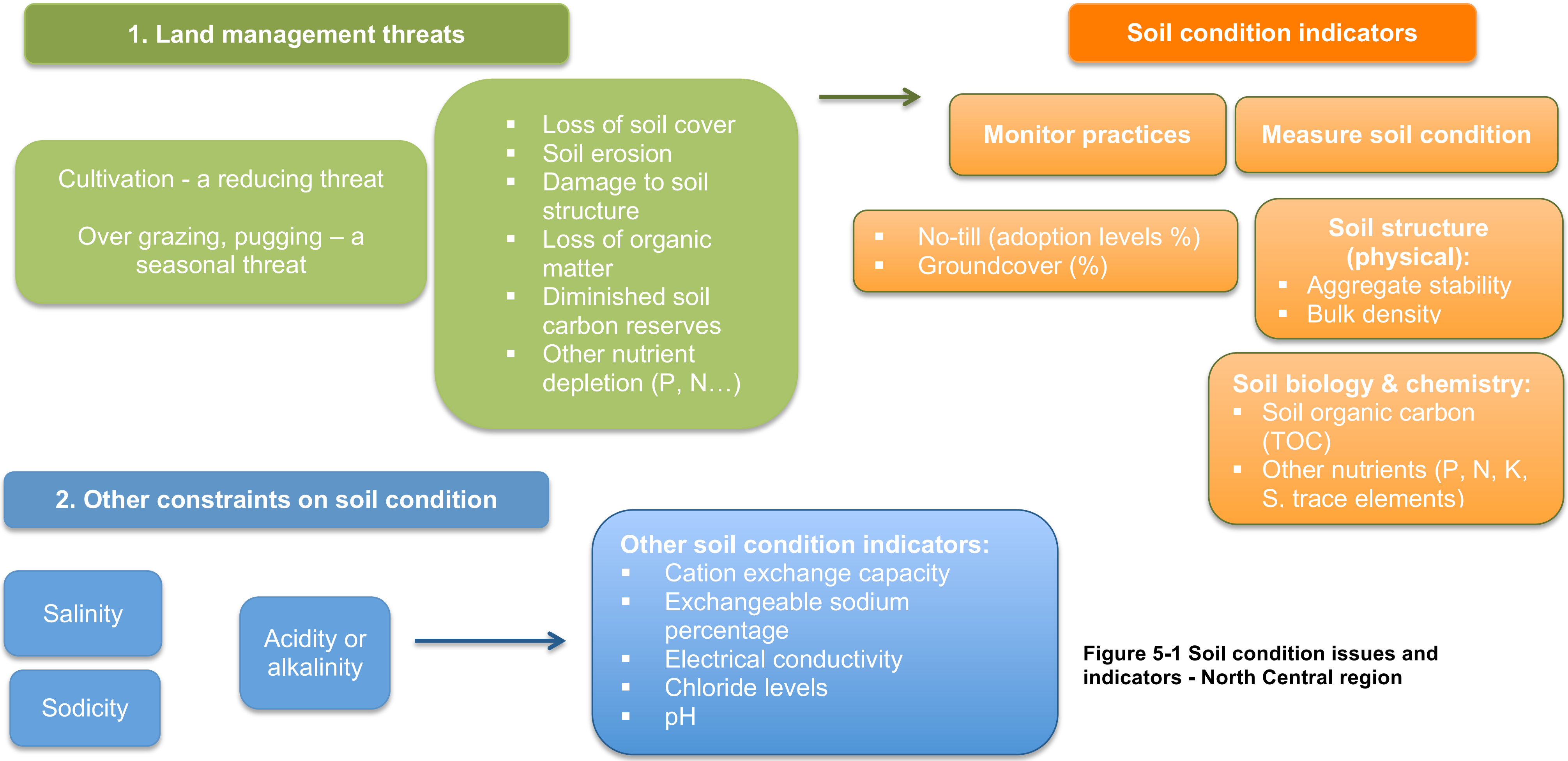

Figure 5-1 Soil condition issues and indicators - North Central region

5.1 Selection of potential indicators

The focus of this study is to recommend measuring methods to assess and monitor the condition and health of regional soils. The main soil condition or health issues in the region can be summarised as:

1. Loss of organic carbon including soil fauna and flora
2. Soil structure decline
3. Soil loss through erosion
4. Nutrient imbalances
5. Acidification
6. Salinity and sodicity.

From an agricultural production perspective these soil conditions lead to reduced water storage and use efficiency, and reduced nutrient storage and use efficiency, negatively impacting crop growth. The review has identified a suite of key indicators that can be relatively easily measured and that have the potential to monitor soil condition over time (on farms) in the North Central region. These potential soil condition indicators are outlined in Table 5-1. These include chemical indicators (of soil salinity, sodicity, alkalinity/acidity and nutrient status), biological indicators (of organic matter levels/organic carbon), physical indicators (of soil aggregation and aggregate stability) and soil loss and its potential (using surrogate measures of ground cover and tillage practice).

Table 5-1 Potential soil condition indicators

Soil condition indicators			
Chemical indicators	**Biological indicators**	**Physical indicators**	**Soil loss indicators**
Salinity	**Organic matter**	**Soil structure**	**Erosion and risk**
Electrical conductivity (EC) Chloride levels	Total organic carbon Labile carbon	Aggregate stability Bulk density Penetration resistance	Dust levels Ground cover (%) Texture Tillage practices
Sodicity			
Cation exchange capacity (CEC) Exchangeable sodium percentage (ESP) Electrochemical stability index (ESI)			
Alkalinity/acidity			
pH			
Nutrient status			
Total Phosphorus Phosphorus buffer index Total Nitrogen (Available) Potassium (Available) Sulphur Trace elements			

The following sections define and describe various measuring methods for these indicators.

5.2 Biological and chemical indicators

The most relevant biological and chemical indicators are:

5.2.1 Total organic carbon / organic matter

Organic matter is composed of plant and animal residues, which are at different stages of decomposition. Soil organic matter has an effect on many soil properties, including soil structure, water holding capacity and the availability of nutrients. As such the presence or lack of organic matter can have a significant impact on the productivity of the soil.

While it is a useful indicator of soil health it is difficult for laboratories to measure. Since organic carbon makes up approximately 50% of organic matter and is easier for labs to test, organic carbon is normally measured in place of organic matter. A conversion factor of 1.72 is commonly used to convert organic carbon to organic matter; this assumes that the organic matter contains 58% organic carbon.[10]

Total organic carbon is a common test and requires no distinctive sampling practices.

5.2.2 Labile carbon

Although significant amounts of organic carbon are present in the soil, a large percentage of it is relatively inert. To gain a better understanding of the availability of carbon in the soil, the total organic carbon can be divided into three fractions based on decomposability (‘passive’, ‘slow’ and ‘labile’). The passive and slow fractions have relatively slow turnover rates (2500 years and 20-40 years respectively) and respond more slowly to changes in agricultural practices than the more available labile fraction.

The labile fraction has a relatively quick turnover time (2-3 years) and is readily available for use by microorganisms. It is considered to be a more sensitive indicator of changes in soil quality and function than total organic carbon, which includes all forms of carbon. Labile carbon results from the addition of fresh residues such as plant roots and living organisms. While it composes only 1-5% of soil organic matter, it is more sensitive to changes in management practices and allows significant differences to be detected earlier than it would be if only total organic carbon were measured.[11]

The Soil Carbon Research Project (SCaRP) project[12] has developed a simple, fast and inexpensive technique for determining the allocation of soil carbon to these fractions, using mid-infrared (MIR) spectroscopy.

5.2.3 Cation Exchange Capacity (CEC)

The cation exchange capacity is a measure of the soils ability to capture cations (positively charged ions). The ability for the soil to capture cations is important as they effect how the soil reacts when exposed to water and the plants ability to extract nutrients from the soil.

[10] Soil Quality Pty Ltd (2014) Total Organic Carbon [Cited 18 May 2014.] Available from URL: www.soilquality.org.au
[11] Soil Quality Pty Ltd (2014) Labile carbon [Cited 18 May 2014.] Available from URL: www.soilquality.org.au
[12] http://www.csiro.au/en/Outcomes/Climate/Understanding/Measuring-Carbon-In-Soils.aspx

There is also a relationship between CEC and the soils level of organic matter, and CEC can act as an indirect measure of soil organic matter. Higher CEC readings usually mean that the soil has more clay and organic matter. Therefore soils with higher CEC generally have greater water holding capacity than soils with low CEC.[13,11]

CEC is a common test and requires no distinctive sampling practices.

5.2.4 Exchangeable Sodium Percentage (ESP)

In high concentrations sodium has a detrimental effect on soil structure and plant growth. ESP is a measure of the balance between sodium (Na) and the sum of the exchangeable cations (CEC). It is found by dividing the exchangeable Na by the CEC, the answer is expressed as a percentage. The higher the percentage the more dispersive the soil is. Soils with an ESP of >6 are considered to be sodic.[14]

ESP is a common test and requires no distinctive sampling practices.

5.2.5 pH

Understanding the pH of soil is important as it controls many chemical processes and affects the availability of nutrients to plants by controlling the chemical form the nutrient takes. pH measures the acidity or alkalinity of the soil by measuring the concentration of potential hydrogen ions.

The optimum range of pH for most agricultural species is between 5.8 and 7.5. At a lower pH the soils become increasingly acidic, which can affect the availability of water and nutrients to plant roots. While at higher pH plant growth can be reduced because water and nutrients aren't able to easily penetrate the soils. [11]

pH is a common test and requires no special sampling practices.

5.2.6 Electrical Conductivity (EC)

Plants extract water from the soil profile by exerting an absorptive force greater than that which holds the water to the soil. Salt in the soil water increases the force the plant must exert to extract water (this additional force is referred to as the osmotic effect). Due to this, high levels of salt in the soil profile can cause some plants to suffer from a shortage of water even if there is sufficient water in the soil profile.

Electrical conductivity is a measure of soil salinity. It works by passing an electrical current through a sample of the soil solution. Salts increase the ability of a solution to conduct electricity, therefore a high EC reading indicates high soil salinity.

The common method of assessing soil salinity is by preparing a soil water solution at the ratio of 1:5 soil:water and using a salinity meter to pass an electrical current through the sample. This method is referred to as $EC_{1:5}$.

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[13] Soil Quality Pty Ltd (2014) *Cations and Cation Exchange Capacity* [Cited 18 May 2014.] Available from URL: www.soilquality.org.au
[14] Wrigley, R. & Dillon, C. *Soil Testing? Guidelines For The Interpretation Of Soil Chemistry Analysis Results.*

ECe (electrical conductivity of the saturation extract) is considered to be more accurate method than $EC_{1:5}$, however it is more expensive and the results from the $EC_{1:5}$ method can be multiplied by a field texture factor to determine the approximate ECe value.[15]

5.2.7 Electrochemical Stability Index (ESI)

ESI is a measure of the dispersive potential of a soil. It measures the relationship between soil salinity and sodicity, both of which can impact soil stability. Generally sodic soils would be considered dispersive, however when this is combined with high soil salinity soil dispersion decreases. Therefore it is helpful to assess these parameters together, and ESI quantifies the relationship between these two parameters.[16]

5.2.8 Nutrient levels, especially phosphorus, potassium, sulphur and trace elements

Phosphorus

Phosphorus is essential for plant growth and due to the nature of Australian soils this element can be in short supply. Phosphorus deficiency can cause stunted growth, leaf distortion, chlorotic areas, reduced yield and delayed maturity. [12]

The main methods used to measure soil phosphorus are:

- Colwell, recommended for soil pH <7.4.
- Olsen, recommended for soil pH >7.4.
- Mehlich recommended for a wide range of pH (provides a P saturation index similar to PBI).

Phosphorus buffer index (PBI)

Phosphorus applied as fertiliser reacts with the soil and becomes less available for plant uptake, the extent to which these reactions occur depends on the phosphorus buffering capacity of the soil. A soil with a high phosphorus buffering capacity will require more phosphorus fertiliser than a soil with a low phosphorus buffering capacity in order to be productive.[17]

This test is now inexpensive to perform.

Nitrogen

All plants, with the exception of those that fix nitrogen, require nitrogen to survive. It plays an essential role in the production of chlorophyll; as such any deficiency in nitrogen will cause a yellowing of the leaves. If it is not addressed it can ultimately lead to a reduction in plant growth.[18]

[15] Soil Quality Pty Ltd (2014) *Phosphorus* [Cited 18 May 2014.] Available from URL: www.soilquality.org.au
[16] AgVita Analytical (2008) Electrochemical Stability Index (ESI) [Cited 30 May 2014.] Available from URL: www.agvita.com.au/pdf/expresssoil/expresssoilelectrochemicalstabilityindex.pdf
[17] DPI (2012) *Interpreting Soil and Tisue Tests* [Cited 2 August 2012.] Available from URL: www.dpi.vic.gov.au/agriculture/dairy/pasture-managament/fertilising-dairy-pastures/chapter-8
[18] Soil Quality Pty Ltd (2014) *Nitrogen* [Cited 18 May 2014.] Available from URL: www.soilquality.org.au

Nitrogen exists in the soil in many different forms and readily changes from one form to another. Due to the volatile nature of nitrogen, soil tests are rarely the sole tool used for nitrogen management. Soil results are usually used in conjunction with leaf analysis and nutrient budget calculations (which take into account plant demand, applied nitrogen and nutrient removal).[19]

Soil nitrogen can be measured in the following ways:

- Total nitrogen (total Kjeldahl Nitrogen (TKN)) – measures all nitrogen present in the soil, not all of which is available to plants.
- Nitrate nitrogen (NO_3^-) and Ammonium nitrogen (NH4+) – includes only the forms of nitrogen available to plants.

Available Potassium

Potassium is essential for plant growth and plays a major role in the regulation of water in plants, both the uptake through the plant roots and its loss through the stomata. A deficiency in potassium may cause stunting or slow growth, poor resistance to temperature change and drought and defoliation.

There are two main soil tests available for potassium, Colwell and Skene. The tests produce similar results and have similar costs.[13]

Available Sulphur

Sulphur is a mobile nutrient that can move rapidly through the soil profile, especially in sandy soils. Sulphur deficiency results in pale green chlorosis throughout the plant, severe stunting accompanied by reduced leaf size and reduced branching.

The main methods of testing available sulphur are:

- CPC sulphur (calcium dihydrogen phosphate plus charcoal-extractable sulphur), this method measures sulphate sulphur only.[14]
- Blair sulphur test (KCl 40) provides a better indication of the sulphur status as it takes into account some of the sulphur that will become available from the breakdown of organic matter.[20]

5.3 Soil physical indicators

The most relevant physical indicators are:

5.3.1 Soil structure indicators

Soil aggregation, aggregate stability

Changes in aggregate stability can act as an early indicator of changes in soil health.

[19] Wrigley, R. & Dillon, C. *Soil Testing? Guidelines For The Interpretation Of Soil Chemistry Analysis Results.*
[20] DPI (2012) *Interpreting Soil and Tissue Tests* [Cited 2 August 2012.] Available from URL: www.dpi.vic.gov.au/agriculture/dairy/pasture-managament/fertilising-dairy-pastures/chapter-8

Aggregate stability refers to the ability of the soil aggregates to resist disintegration when exposed to forces such as tillage, water or wind erosion. This process is dependant on a number of elements including, soil texture (clay content and type), the presence of binding agents such as iron and silica, the organic matter content, and exchangeable sodium (the greater the ESP the more dispersive the soil).

Stable soil aggregates indicate the presence of organic matter, biological activity, and nutrient cycling through the soil, all of which are indicators of good soil health. In addition, soils with a large number of soil aggregates have more pore spaces then poorly aggregated soil, because pores are present within and between the soil aggregates. Pores are essential for the entry of water and air into the soil and the movement of biota and nutrients within the soil. They also provide zones of weakness for root growth and penetration.

Soils with poor soil aggregation may form soil crusts and have few pores. This can prevent infiltration, increase bulk density, and limit the water holding and air exchange capacity of the soil.

There are a number of different methods of assessing aggregate stability including the following:

- Gentle hand sieving to determine dry aggregate status (using eight replicates in a 20 x 20 m area) - relates directly to the wind erodability of the soil. This method is quick, requires the minimum amount of specialist equipment and can be done in the field.[21]
- Repeated rotary sieving – is appropriate for the assessment of the stability of aggregation during cultivation, and erosion events. Difficult to perform in the field.
- Elutriation – is the process of passing air through a sample of soil at a range of velocities. And measures the susceptibility of the soil to wind erosion. This method doesn't involve particle abrasion and the particles do not have to fit the shape of the holes in the sieve. It is the least aggressive method.[22] However, elutriator's are not commonly available, making the test more costly than the other methods.
- Water Stable Aggregate (WSA%) – this is a measure of the aggregate stability when wet or hit by raindrops. It is also an indicator of the soil's resistance to compaction.[23] However, the only laboratory able to perform the test is in Tasmania, and it is relatively expensive.

Dispersion and slaking

Slaking is the breakdown of a soil aggregate on wetting, while dispersion is the separation of soil into single particles. Soils that slake into very fine fragments can set hard on drying, forming a crust that can reduce infiltration and affect the plants ability to become established. Dispersive soils have unstable structures and pores below the surface can become blocked by dispersed soil particles. These soils are likely to swell strongly when wet which also restricts the movement of air and water through the soil profile.

[21] CSIRO (2002). Measurement of size distribution of aggregates in dry soil (J. F Ley)
[22] McKenzie, N., Coughlan, K. & Cresswell, H. (2002) *Soil Physical Measurement and Interpretation for Land Evaluation.* CSIRO, Collingwood, Vic.
[23] Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Moebius, B.N., Thies, J.E. and Abawi, G.S. (2007) *Cornell Soil Health Assessment Training Manual, Edition 1.2.2*, Cornell University, Geneva, NY.

There are a number of different methods of assessing the dispersive/slaking potential of a soil, including:

- Aggregate stability in water test (ASWAT) – measures the soils dispersive potential. Several dry soil aggregates, 3-5mm in diameter, are placed in distilled water and over a period of 2 hours the level of dispersion and slaking is assessed.
- Emerson dispersion test - An air dried aggregate and the same soil reworked at field capacity are placed in a dish of deionised water. After 2 hours and 20 hours their appearance is assessed for slaking and dispersion. If no dispersion is observed the air dried aggregate and distilled water are shaken for 10 min and left to stand for 5 min. The appearance is then assessed to determine if the sample is dispersed or flocculated. This is a standard laboratory test and can be performed along with the chemical analysis of the soils.

Compaction, porosity and pore size distribution

Compaction occurs when a force compresses the soil and pushes the air and water out of the soil profile, causing the soil to become denser. Compaction can affect plant growth by restricting the number of pores in the soil, which affects root movement, infiltration, drainage and the circulation of air.

Porosity relates to the pore spaces located within the soil that can be filled with either water or air. The number of pores is not the only factor to consider. The size and connectivity are also important. The larger pores enable root growth and the movement of air and water, while the smaller pores (<0.2 μm) hold water so tightly that plants or soil organisms can't use it.[24]

There are a number of ways to measure the compaction and porosity of a soil, including the following:

- Bulk density (BD) – measures the compaction of the soil and this measure can also be used to infer the relative porosity of the soil, as porosity is inversely related to bulk density (as the BD increases the porosity decreases).

  BD is the dry weight of soil divided by the total soil volume (the total soil volume includes the volume of solids and pores). The most common method of measuring BD is by collecting an intact core of known volume from the site. This is done by pushing a metal ring into the ground to a predetermined depth and recording the weight of the sample after drying.[25]
- Penetration resistance – indicates the bulk density and compaction of the soil. It is a measure of the soils strength and resistance to penetration. The test is relatively easy to perform and it can be measured in the field using a steel rod, or penetrometer[26].

5.4 Soil loss indicators

Erosion risk is a result of inherent soil factors, landscape features and soil conditions / exposure as a result of land management.

[24] DEPI (2011) *Porosity* [Cited 2 June 2014] Available from URL: www.vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_soil_structure_porosity
[25] Soil Quality Pty Ltd (2014) *Bulk Density* [Cited 18 May 2014.] Available from URL: www.soilquality.org.au
[26] SANTFA (2002) Measuring soil compaction and hardpans: penetration resistance MPa = mass (kg) x 1.1826

5.4.1 Site and soil characteristics

Slope length and steepness, exposure

The steepness and length of slope affect the erosion potential of a site. The steeper the slope the greater the erosion potential, and the longer the slope the higher the erosion potential.

This information can be obtained from topographic maps of the area.

Soil texture

Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils.

Soil texture can be easily measured in the field or by a lab.

Soil structure

Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Refer to section 4.3 for further detail.

Organic carbon content

Organic carbon provides a food source for microorganisms and due to this can help to improve soil structure and reduce the erosion potential of the soil. This is because microorganisms help to bind the soil particles together into aggregates that are more resistant to erosion. Refer to Section 5.2.1 for further detail.

5.4.2 Land use, soil management and vegetation cover / condition

Groundcover % and timing

Soil erosion potential increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant cover helps to protect the soil from the impact of rain and wind, slows down surface runoff and allows excess surface water to infiltrate. It also helps the soil retain moisture during the summer months, improves infiltration and adds organic matter, which in turn helps to improve the moisture holding capacity and plant growth in the soil.

Remotely sensed satellite imagery (MODIS) has been used by DEPI[27] to assess erosion potential in Victoria given that erosion potential can be affected by land management that influences ground cover levels or the amount of exposed bare soil. The erosion potential after the end of the growing season has been modelled using land cover and Enhanced Vegetation Index (EVI) data. The main land cover types: pasture, annual crops, woody vegetation and bare ground, have very different phenological characteristics and it is expected that these will be able to be mapped with more confidence in the near future, after further ground truthing.

[27] DPI (2011). Final report – Soil assets and NRM investment (Macewan et al)

Groundcover can also be assessed onsite at any point during the year. This would give an idea of the quality of ground cover at a particular point in time, and would be accurate for that location only. There are a number of ways to assess this, all of which are straightforward and easy to perform.

- Quadrat method – using a metal square of at least 0.5 m^2 in area, record the percentage cover of living and dead vegetation, at between 10-200 random spots within the assessment area.
- Step point method[28] – mark out a random transect across the assessment area, make a 1mm wide mark on each boot and walk across the paddock following the transect. At each step record the presence of any vegetation (living or dead), which falls immediately in front of the mark. Repeat this 50 times per hectare.

Tillage intensity and timing

This relates to the intensity of tillage (or cultivation) and its effect on ground cover during risky time periods (dry or wet periods). This can be measured by observations and farmer surveys.

Grazing management

This also relates to ground cover during risky time periods (dry or wet periods), and can be assessed through observation and farmer surveys.

[28] MSF (2006). Estimating groundcover and soil aggregation for wind erosion control on cropping land (McIntosh, Leys and Biesage – Mallee Sustainable Farming Inc. Fact Sheet 26)

PART B SOIL CONDITION ASSESSMENT METHODS

6 Practical methods to assess and monitor the condition and health of regional soils

6.1 Overview

RMCG recommends selected, practical and cost effective measuring methods to assess several main elements of soil health and condition in the North Central region over time. The overall framework for our recommended approach is to establish ten reference sites, and use a standard soil sampling method (four rotating transects per site). It is proposed that these methods be adopted to monitor changes in:

1. **Soil organic matter** – by measuring total organic carbon using standard laboratory soil analysis, depths and sampling methods.
2. **Soil chemistry** – by measuring ten specific chemical properties using standard laboratory soil analysis, depths and sampling methods.
3. **Soil structure** – by measuring two physical properties (aggregate stability and penetration resistance).
4. **Soil erosion risk** – by measuring soil loss directly, groundcover percentage and soil texture via recognised field based methods.

Soil monitoring sites should be chosen to be representative of the main soil types where deteriorating soil condition and agricultural production is most prominent in the region. Reference farms could be established to host monitoring sites. An effective way to store, display and share soil condition information would be through a web based interactive mapper. Data would need to be stored in a manner that would maintain its integrity in the long term.

6.2 Reference sites

It is recommended that long term monitoring sites be established at up to ten locations across the North Central region. These should be focused in areas supporting the more arable agricultural soils rather than in the steeper less arable terrain in the highlands areas of the four main catchments. Farming for Sustainable Soils group members (existing and past) could be approached to host sites in the first instance. There is already good baseline soil chemistry, including organic carbon, data available from soil testing on members' properties over the past five years. A list of suggested soil types and locations is shown in Table 6-5. These soils exemplify the main soil condition issues present in the north central region. These include, loss of organic matter and carbon, nutrient losses and/or imbalances, sodicity, salinity, acidification, soil structure decline and soil loss.

Table 6-1 Example reference sites for long term soil condition monitoring

No.	Reference sites	Soil description	Soil classification	Location/soils group
1 2 3	Riverine Plains Riverine Plains Riverine Plains	Red duplex (sodic) cropping soils; slightly acidic sandy clay loam surfaces overlying light clays increasing in sodicity with depth	Sodosols	Lockington Serpentine Charlton Normanville
4 5	Mallee soils Mallee soils	Calcareous red brown earths comprising sandy loam to clay loams overlying clay subsoils; alkaline	Carcarosols	Normanville Donald Wycheproof (north)
6 7	Volcanic hills Volcanic plains	Red gradational volcanic cropping soils (clay loams both good and weakly structures)	Ferrosols Sodosols	(e.g. Smeaton) Mid Loddon
8 9	Sedimentary rises Sedimentary rises	Red to yellow/mottled duplex soils; poorer drained/moderately acidic (high Al, Mg and Na)	Kurosols	Natte Yallock Mid Loddon
10	Granite rises	Granitic sands – yellow duplex soils; poorer drained/moderately acidic	Kurosols	Mt Korong Mid Loddon

6.3 Monitoring methods

6.3.1 Standard soil sampling method

A standard soil sampling protocol has been proposed to be conducted at the reference sites. It will be essential to collect repeated measurements at the same site over a long period of time. The differences between the individual samples taken can then be analysed to detect relatively small changes over extended periods, probably decades.

Sampling transects

Within each survey site four transects should be identified. Each transect should be located in an area which is representative of the property, and as far as possible each transect should contain the same soil type, landform elements, slope and aspect. This helps to ensure that the results are representative of the site and are comparable to one another.

A marker should be placed on a fence post at the beginning of each transect. The coordinates of this point should then be recorded using a GPS, to assist with future location of the site.

The transect should begin 15 m from the marked point on the fence line and continue for a minimum of 100 m into the paddock.

Sampling protocol

Prior to starting the fieldwork the sample bags should be labelled with the transect ID and the depth of the sample to be collected.

One composite sample should be collected from two of the four identified transects each year.

Sub-samples should not be selected from areas that are not representative of the area being assessed (e.g. stock camps, water troughs, gateways, tracks, dung heaps).

Topsoil

Each topsoil composite sample should comprise at least 20 sub-samples, collected at regular intervals along the transect. A push tube should be used to collect the subsamples (see **Figure 6-1**).

The topsoil subsamples should be collected from the top 0-10cm of soil. Once all of the subsamples are collected they should be mixed together and the resulting 500g (approx.) composite sample should be placed in the appropriate sample bag to be sent to the laboratory.

Figure 6-1: Topsoil sampler

Subsoil

Each subsoil composite sample should comprise at least 5 sub-samples, collected at regular intervals along the transect. A four-inch hand auger should be used to collect the subsoil subsamples (refer to Figure 6-2).

Ideally the subsoil samples should be collected from the top of the B-horizon, however, where it is not distinguishable the subsamples should be collected from a nominal depth of approximately 30-40 cm. Once all of the subsamples have been collected they should be mixed and a 500g composite should be selected and placed in the appropriate sample bag to be sent to the laboratory.

Figure 6-2: Subsoil sampler (four-inch hand auger)

Timing

In order to ensure the best conditions for soil sampling, the samples should be collected in early autumn each year, prior to the application of fertiliser or other soil ameliorate.

6.3.2 Soil organic matter

The recommended method for sampling and testing Total Organic Carbon is outlined in Table 6-2.

Table 6-2. Analysis and sampling method for assessment of Total Organic Carbon

Indicator	Method of analysis	Sampling protocol
Total Organic Carbon	Combustion: In order to quantify the amount of organic carbon in a sample the organic matter needs to be destroyed. The sample is heated to a high temperature converting the organic carbon to CO_2. The amount produced is measured and this is directly proportional to the concentration of carbon in the sample.[29]	Refer to Section 6.3.1 for detail
	Mid Infrared (MIR) spectrometry: Uses light and heat energy of varying wavelengths, when it is focussed on a sample it causes the molecules in present to increase their vibrational energy based on their molecular geometry, bond strengths and atomic masses. This produces a 'signature' of the molecular composition.[30] The MIR can be used to predict a wide range of soil properties including: ▪ TOC ▪ Total N ▪ Exchangable cations ▪ CEC ▪ PBI ▪ pH ▪ EC ▪ ESP ▪ Bulk density Currently some questions remain on the amount of calibration required with this system, however, it is worth investigating more closely.	Direct contact with the CSIRO MIR laboratory staff is required before submitting the samples. The technology is also getting close to being portable and suitable for infield use.

6.3.3 Soil chemistry

The recommended method for sampling and testing several chemical properties is outlined in Table 6-3.

29 Schumacher, B. A. (2002) *Methods For The Determination Of Total Organic Carbon (TOC) In Soils And Sediments.* United States Environmental Protection Agency. Las Vegas.

30 CSIRO (2013) *Infrared Soil Analysis Laboratory – Adelaide, South Australia* [Cited 10 June 2014.] Available from URL: http://www.clw.csiro.au/services/mir/what.html#predicting

Table 6-3. Analysis and sampling method for assessment of chemical properties

Indicator	Method of analysis	Sampling protocol
Cation Exchange Capacity (CEC)	Standard laboratory test	Refer to Section 6.3.1 for detail
Exchangable Sodium Percentage (ESP)	Laboratory test	
pH	pH (water): Laboratory test	
	pH ($CaCl_2$): Laboratory test	
Electrical Conductivity (EC)	$EC_{1:5}$: Laboratory test	
Electrochemical Stability Index (ESI)	ESI: Laboratory test	
Total Phosphorus	Olsen: Laboratory test	
	Mehlich 3: Laboratory test	
Phosphorus Buffer Index (PBI)	Laboratory test	
Available Potassium	Laboratory test	
Available Sulphur	Blair sulphur test (KCl 40): Laboratory test	
Total Nitrogen	TKN, Nitrate nitrogen (NO_3^-) and Ammonium nitrogen (NH4+): Laboratory test	

6.3.4 Soil structure

The recommended methods for measuring aggregate stability and penetration resistance are outlined in Table 6-4.

Table 6-4. Measurement methods for aggregate stability and penetration resistance

Indicator	Method of analysis	Sampling protocol
Aggregate stability	Water Stable Aggregate (WSA%): currently this test (using the Cornell University devised method) can only be performed at one lab in Australia. This makes the test expensive (refer to p. 21 for further details).	
	Emerson dispersion test: An air dried aggregate and the same soil reworked at field capacity are placed in a dish of deionised water, after 2 hours and 20 hours their appearance is assessed for slaking and dispersion. If no dispersion is observed the air dried aggregate and distilled water are shaken for 10	Refer to Section 6.3.1 for detail

Indicator	Method of analysis	Sampling protocol
	min and left to stand for 5 min. The appearance is then assessed to determine if the sample is dispersed or flocculated.[31] This is a standard laboratory test and can be performed along with the chemical analysis of the soils.	
Penetration resistance	Penetration resistance: is measured using a penetrometer. As the device is pushed through the soil profile at a rate of approximately one inch per second it measures the resistance in psi. Penetration resistance is generally measured at two depths (0-10 cm and 10-40 cm), so that the surface and subsurface soil compaction can be assessed. Record the highest pressure reading of each of the two depths.[32] There are more sophisticated penetrometers that will automatically record the psi through the profile; this provides a greater degree of accuracy.	Within each survey site, readings should be taken when the profile is at field capacity. If the soil is too wet or dry it can lead to an inaccurate assessment of soil compaction. To test if the soil is at field capacity firmly squeeze a handful of soil, if no free water appears on the outside of the soil but a wet outline of the ball is left on your hand the soil is at field capacity. There are now devices available that can add water to bring the core to field capacity.
Bulk density	Bulk density: While this test is helpful it is not recommended as it is expensive to analyse and sampling is difficult and time consuming. Penetration resistance provides an indication of bulk density.	

6.3.5 Soil erosion and risk

The recommended methods for monitoring soil loss and groundcover percentage are outlined in Table 6-5. Monitoring tillage practices can also assess soil erosion risk. There has been a rapid move to no-till cropping systems on the northern plains and in the north western part of the region, thereby substantially reducing wind erosion. Farmers in other cropping districts are also transitioning to reduced and nil cultivation at varying levels.

Table 6-5. Measurement methods for soil loss and groundcover percentage

Indicator	Method of analysis	Sampling protocol
Soil loss (actual)	Using DustTrak: this is a device that measures aerosol concentration. It can be used to determine the amount of soil lost due to wind erosion.	Once set up the devise can be monitored remotely.
	Dust Watch program: There are currently 44 dust monitoring stations across southern Australia. One of which is located on the Loddon Plains.[33]	The data is available to members of the program from - http://www.dustwatch.edu.au/index.php/modelled-wind-

[31] Department of Sustainable Natural Resources (2013) *Soil Survey Standard Test Method, Emerson Aggregate Test.* [Cited 16 June 2014] Available from URL: http://www.environment.nsw.gov.au/soils/testmethods.htm
[32] Soil Quality Pty Ltd (2014) *Field Penetration Resistance* [Cited 2 June 2014.] Available from URL: www.soilquality.org.au
[33] DustWatch Australia (2014) *Community DustWatch Network* [Cited 2 June 2014.] Available from URL: http://www.dustwatch.edu.au/index.php/community-dustwatch/community-dw-network

Indicator	Method of analysis	Sampling protocol
	If the installation of further dust monitoring stations is not practical, access to the information provided by this program may be sufficient to provide an indication of the potential soil loss in the area over a given period.	erosion/regional-erosion
Groundcover % - regional assessment	MODIS satellite: provides information on vegetation canopy greenness, leaf area, and canopy structure over time and space. The enhanced vegetation index (EVI) is derived from this information, and can be used to determine the percentage groundcover on a regional scale.[34]	It is recommended that two satellite images of the study area be obtained each year. One in the summer and one in winter. This would allow the regional groundcover to be assessed in both the winter and summer months.
- paddock scale assessment	Step Point Method: 50 samples, recording the presence or absence of plant cover (living or dead), are collected per hectare. With the presence of plant cover signifying a 'hit'. The number of 'hits' is divided by the total number of samples taken to give the % of groundcover for the area[35].	Sample along transects within the survey site. Make a 1mm wide mark on the toe of each boot. Walk across the study area following a pre determined transect. Take 50 samples (steps) per hectare with a max of 500 samples per study area. At each step record the presence or absence of any vegetation (living or dead) that falls immediately in front of the mark on the leading boot.[34]
Soil texture	Field method based on *McDonald et al. (1998)*[36]: This document provides a method for assessing soil texture in the field. A copy of the breakdown of field texturing categories is provided in Appendix 1.	Sample along transects within the survey site. Take a small handful of soil and add enough water to form a ball. Feel the texture of the soil with your hands to determine if it is gritty (sand), silky (silt) or plastic/sticky (clay). Record the result. Reroll the ball and place it between your thumb and forefinger. Using your thumb gently press it out over your forefinger to form a hanging ribbon, approximately 2mm thick and 1cm wide. Measure and record the length

[34] DPI (2011). Final report – Soil assets and NRM investment (Macewan et al)
[35] University of Idaho (2014) *Measuring Plant Cover* [Cited 2 June 2014.] Available from URL: http://www.webpages.uidaho.edu/range357/notes/cover.pdf
[36] McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1998) *Australian Soil and Land Survey Field Handbook*. Australian Collaborative Land Evaluation Program: Canberra.

Indicator	Method of analysis	Sampling protocol
		of the ribbon. If the soil has a high clay content (i.e. can form a ribbon of ≥7 cm) mould the soil into a rod. Check if the rod can be formed into a ring.[37] Use the field guide to soil textures provided in Appendix 1 to classify the soil.

6.4 Data storage and accessibility

An effective way to store and display soil condition information is through an online interactive mapper. There are currently a number of these programs up and running. For this project it may be possible to add data to one of the pre-existing systems, or to use these programs as a stepping stone to develop a new independent system specific to meet the needs of the North Central CMA.

The Soil Quality website[38] allows the user to examine soil properties across Australia's agricultural regions. The purpose of the website is to establish benchmark sites and it provides the basis of an ongoing soil quality monitoring and education program. It is an online interactive map, which provides user-friendly access to information on the physical, chemical and biological properties of soils on a regional basis for each state. It also provides the ability to compare soil test results from any farm with results already stored in the system. Results for a range of soil quality parameters, as outlined in Table 6-6, are stored in the data base.

Table 6-6. Soil quality parameters

TOC (various depths)	CEC	Electrical conductivity (ECe)
Carbon stock	Total N (various depths)	Phosphorus (Colwell Phosphorus, PBI and DGT Phosphorus)
Microbial Biomass Carbon	Nitrogen stock	Water Repellency
Soil Nitrogen Supply	pH(CaCl2)	Bulk density (various depths)
Disease (Take-all and Rhizoctonia)	pH (water)	Gravel content (various depths)
Nematodes (Cereal Cyst Nematode, P. neglectus (RLN) and P. thorneii (RLN))		

[37] Soil Quality Pty Ltd (2014) *Soil Texture – Measuring in the Field* [Cited 2 June 2014.] Available from URL: www.soilquality.org.au

[38] http://www.soilquality.org.au. The project is supported by the GRDC, Australian Government Department of Agriculture, CSIRO, NSW DPI, Murray CMA and others

Critical values have been defined for each of the parameters listed above, these values relate to the point at which the concentration of the parameter will impact the productivity of the soil. This site uses a 'traffic light' system, based on these critical values, to make the interpretation of soils data quick and efficient. **Figure 6-3** illustrates some examples of outputs from the site:

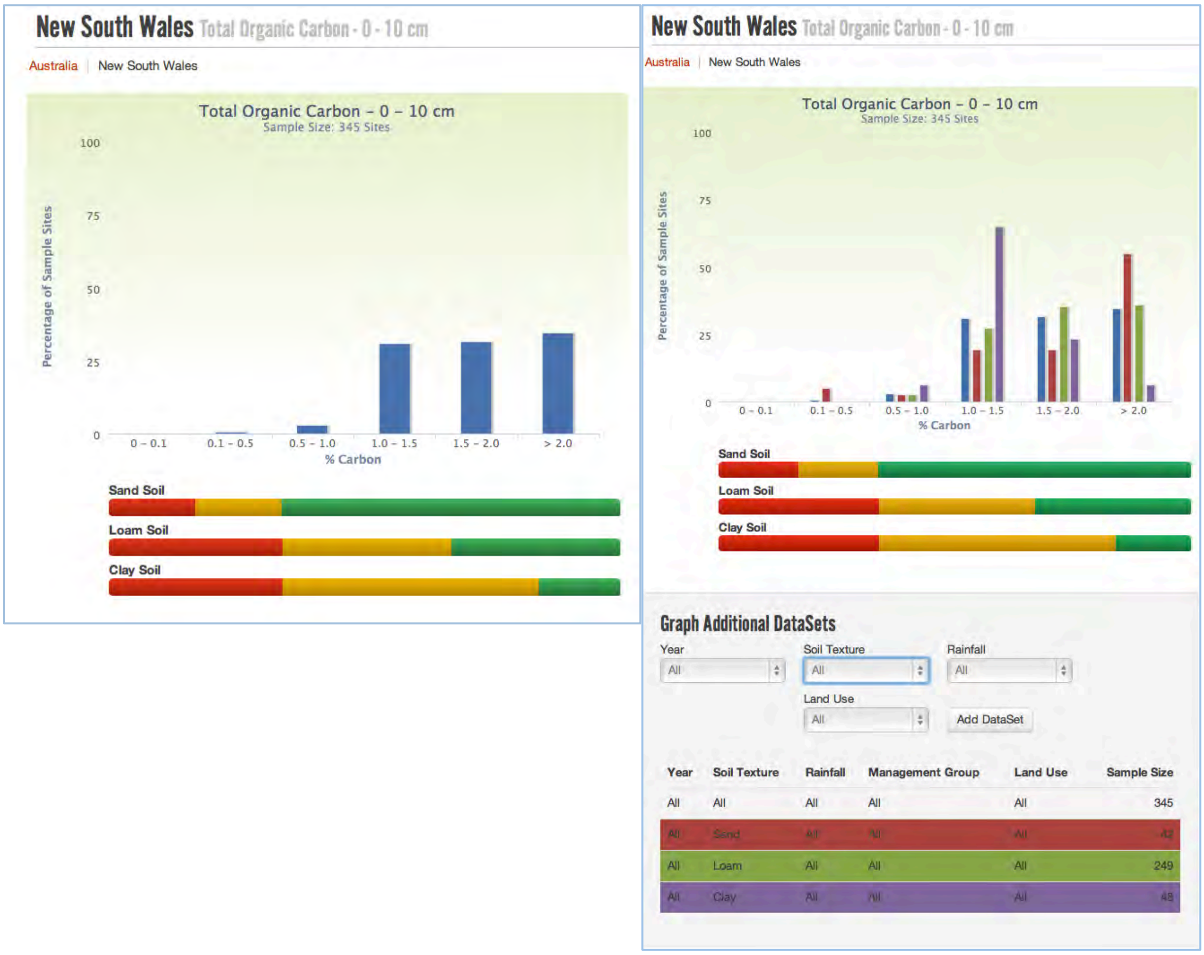

Figure 6-3: Results for TOC in the topsoil for NSW. Left – Total percentage of sites within each category. Right – Sites by soil texture within each category. (http://www.soilquality.org.au/au/nsw/examine/state/total-carbon-0-10)

The charts in Figure 6-3 display the results for Total Organic Carbon at a depth of 1-10cm (topsoil) for NSW. There are currently 345 sites with data on this parameter in NSW.

The bars under the chart indicate the critical values for the selected parameter. These vary based on soil texture for TOC, as soils with heavier textures, such as clay and loam soils, have a greater capacity to store organic carbon.[39] Therefore, sandy soils are within the healthy range for organic carbon at a lower concentration than a clay or a loam soil.

The chart to the left displays the results from all of the sample sites within NSW. This data shows that the sampled sites are generally within or just outside of the healthy range for organic carbon.

[39] Soil Quality Pty Ltd (2014) *New South Wales Total Organic Carbon* – 0-10 cm [Cited 2 June 2014.] Available from URL: www.soilquality.org.au

This data can also be broken down by year, soil type, rainfall and land use, to provide a more detailed understanding of the information. The chart to the right provides an example of this, indicating that most of the sites with clay topsoils have organic carbon between 1.0 and 1.5 and that most of the sites with sandy topsoil fit into the >2.0% organic carbon category.

It is also important to note that the number of sites with each soil texture varies greatly. Sites with loam topsoil make up the largest percentage with 249 sample sites, while the sand and clay topsoils have a sample size of 42 and 48 respectively. Farmer group based data could also be assessed against other data sets within a region or across the State as a whole.

7 Conclusions

This study has recommended practical indicators and measuring methods to assess and monitor the condition and health of soils in the North Central region over time. Suitable sampling protocols and monitoring regimes have been recommended to ensure comparable results over time. It will be essential to collect repeated measurements at the same site over a long period of time. The differences between the individual samples taken can then be analysed to detect relatively small changes, some of which will only become detectable over extended periods, probably decades. The review has considered the most important soil condition or health issues for each of the main soil types and land uses in the region. These are loss of organic carbon and soil biota, soil structure decline, soil loss through erosion, nutrient imbalances, soil acidification, and salinity and sodicity.

Total organic carbon is the foundational indicator of soil condition. The levels of organic carbon are directly linked to the physical structure and chemical properties of the soil and are a signal of the soil's overall fertility and health. Organic carbon levels have a marked influence on soil colour, aeration, nutrient status, and water holding properties. Total organic carbon is a standard part of soil sample analyses.

Suitable indicators of specific chemical properties of soils that are related to soil salinity and sodicity, soil pH and nutrient status have also been selected. Similarly two physical properties, aggregate stability and penetration resistance, have been selected to monitor changes in soil structure. Finally, two indicators of soil erosion risk, groundcover and soil texture, have been identified, as well as a direct measure of soil loss.

The review recommends that these measurements be conducted on ten soil monitoring sites that are representative of the main soil types where soil condition issues and agricultural production is most prominent in the region. The feasibility of establishing reference farms to host monitoring sites should be investigated. An effective way to store, display and share soil condition information would be through a web based interactive mapper. This type of system provides the perfect platform to view changes in soil health over time and space. Data will need to be stored in a manner that will maintain its integrity in the long term. There are currently a number of these programs up and running. For this project it may be possible to add data to one of the pre-existing systems, or to use these programs as a stepping stone to develop a new independent system specific to meet the needs of the North Central CMA.

Changes in soil condition are difficult to monitor because they can occur irregularly and progress very slowly over a long time. The indicators proposed will provide robust information on four indicators of the health of the region's soils – soil organic matter, soil chemistry, soil structure and erosion risk.

As specific purposes for monitoring are better defined (relevant at the regional and/or local level), some or all of these indicators could be monitored depending on the level of resourcing available. Increasing the organic carbon content of regional soils is a goal that has clear benefits, including better structure, increased yields, and carbon storage to mitigate against climate change. It may, however, be more cost effective to monitor the main drivers of soil condition change, such as land management practices, rather than soil condition directly. Similarly, modelling approaches to better understand the relationships between soil condition and land management will also be helpful.

References

ASRIS – accessed 27/5/14. Australian soils resource information system, CSIRO. http://www.asris.csiro.au/mapping/viewer.htm

DNRE (1997a). St Arnaud 1:250000 Geological Survey. Department of Natural Resources and Environment, Victoria.

DNRE (1997b). Swan Hill 1:250000 Geological Survey. Department of Natural Resources and Environment, Victoria.

Kelly, J and Rengasamy, P (2006). Diagnosis and Management of Soil Constraints. University of Adelaide and the Grains Research & Development Corporation.

Loddon Community Working Group (1992). Loddon Catchment Salinity Management Plan, Loddon Community Working Group with assistance from the Department of Conservation and Environemnt, Rural Water Commission and the Department of Food and Agriculture, Victoria.

Lorimer, M.S. (1987). A study of the land in the Campaspe catchment. Department of Conservation, Forests and Lands, Land Protection Division, Victoria.

Nyle C. Brady & Ray R. Weil (2009). Elements of the Nature and Properties of Soils (3rd Edition). Prentice Hall. ISBN 9780135014332.

SCA (1982). A study of the Land in the Catchment of the Avoca River. Soil Conservation Authority, Victoria.

Schoknecht, N. (1988). Land Inventory of the Loddon Catchment: A reconnaissance survey. Land Protection Division, Department of Conservation, Forests and Lands, Victoria.

The Australian Soil Classification: accessed 27/5/14 http://www.clw.csiro.au/aclep/asc_re_on_line/soilglos.htm#ap

Victorian Resources online – accessed 27/5/14. Department of Primary Industries. http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/landform_geomorphology

Appendix 1: Field guide to soil textures[40]

Soil texture	Description	Ribbon Length	Approximate Clay Content (%)
Sand	Coherence nil to very slight, cannot be molded; single sand grains adhere to fingers.	Nil	<5%
Loamy Sand	Slight coherence; sand grains of medium size; can be sheared between thumb and forefinger.	approx. 5 mm	5-10%
Clayey Sand	Slight coherence, sticky when wet; many sand grains stick to fingers; clay stains the hands. Little or no organic matter.	5-15 mm	5-10%
Sandy Loam	Bolus just coherent but very sandy to touch; dominant sand grains are of medium size and are easily visible.	15-25 mm	10-20%
Light sandy clay	Coherent bolus, sandy to the touch; dominant sand grains are of medium size and readily visible.	20-25 mm	15-20%
Loam	Loams can form a thick ribbon. Soil ball is easy to manipulate and has a smooth spongy feel with no obvious sandiness. Greasy to touch if organic matter is present.	approx. 25 mm	approx. 25%
Silty Loam	Coherent bolus; very smooth to silky when manipulated.	approx. 25 mm	approx. 25%
Sand Clay Loam	Strongly coherent bolus, sandy to touch; medium size sand grains visible in finer matrix.	25-40 mm	20-30%
Clay Loam	Strongly coherent plastic bolus, smooth to manipulate and slightly sticky.	40-50 mm	30-35%
Clay Loam, Sandy	Coherent plastic bolus; fine to medium size sand grains visible in finer matrix.	40-50 mm	30-35%
Silty Clay Loam	Coherent smooth bolus; plastic and often silky to the touch.	40-50 mm	30-35% (with silt)
Sandy Clay	Plastic bolus; fine to medium sand grains can be seen, felt or heard in clayey matrix.	50-75 mm	35-40%
Light Clay	Plastic bolus; smooth to touch.	50-75 mm (slight resistance to ribbon shear)	35-40%
Light Medium Clay	Plastic bolus; smooth to touch.	approx. 75 mm (mod. resistance to ribbon shear)	40-45%
Medium Clay	Smooth plastic bolus; handles like plasticine; can be molded into rods without fracture.	>75 mm (mod. resistance to ribbon shear)	45-55%
Heavy Clay	Smooth plastic bolus; handles like stiff plasticine; can be molded into rods without fracture.	>75 mm (firm resistance to ribbon shear)	>50%

[40] McDonald et al. (1998)