Linking and demonstrating soil health outcomes and management practices.

Report to:

Bass Coast Landcare Network

Partner organizations:

DSE ecoMarkets, South Gippsland Landcare Network, Westernport Catchments Landcare Network, DPI – Sustainable Landscapes

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Table of Contents

Executive summary

Scope of project

The overarching aim of this project was to assess the performance of the rapid soil health assessment tool developed by Landcare. The intention was to provide information which could be used in the refinement of the tool, and in the future development of a Soil Health Gain Calculator by the Department of Sustainability and the Environment (DSE).

Approach

This work was undertaken in two discrete, but related, tasks:

Task 1. Working with the Bass Coast, Westernport and South Gippsland Landcare groups, the first task involved the assessment of soils from a range of farms and reference sites. The soils were analyzed for a suite of key soil physicochemical properties, and the results compared to the results of Landcare's assessment of soil health, using their tool.

Task 2. The second task involved an assessment of the different parameters included in the rapid soil health assessment tool developed by Landcare. This task included an in-field assessment of the implementation of the tool by Landcare staff. This task was undertaken using both qualitative and quantitative approaches.

Overview of findings

Task 1: In the assessment undertaken here there was a positive, albeit it relatively weak, relationship between soil health scores and the number of physicochemical properties falling into their desirable range. Furthermore, when specific site comparisons were made, in three of four cases the soil health scores, and four of four cases the number of soil properties in the desirable range, were higher in less disturbed or intensively managed (based on farmer records) sites.

Task 2, Qualitative assessment: The rapid soil health assessment tool developed by Landcare considers a wide range of chemical, biological and physical soil properties. While a good number of the measures require no modification, several opportunities for improvement exist. Some measures have a large degree of uncertainty associated with them, and their inclusion in the tool should be carefully considered. The tool needs to be used with due consideration of the limitations of the method. This will be true of any in-field assessment, or indeed more detailed assessment of soil health. Careful explanation of terms and training of end-users will improve the performance potential of the tool.

Task 2, Quantiative assessment: The level of agreement between some measures in the rapid soil health assessment tool developed by Landcare and more quantitative methods for measurement was low. However, this provides useful information in terms of refining the tool.

Concluding remarks

Measuring soil health in the field is challenging, but is of high priority. Many different approaches for measuring soil health have been developed. Methods for measuring soil health on a large scale will need to be readily implemented in the field, and likely to detect changes in soil health. To this end, the rapid soil health assessment tool developed by Landcare is readily used, and is similar in its approach to that proposed in other contexts. Given the tremendous spatiotemporal variation in soils and soil properties, sampling regimes need to be very carefully designed in any assessment of soil heath. We contend that one of the greatest benefits that can come of measuring soil health is raising awareness of the importance of soil health in the minds of land managers, and the impact that this may have on future land management decisions. Therefore, given all of these challenges associated with measuring soil health, we consider it commendable that Landcare has taken steps to develop a rapid soil health assessment tool.

Scope of project

The overarching aim of this project was to assess the performance of the rapid soil health assessment tool developed by Landcare. The intention was to provide information which could be used in the refinement of the tool, and in the future development of a Soil Health Gain Calculator by the Department of Sustainability and the Environment (DSE). This work was undertaken in two discrete, but related, tasks.

Task 1. Assess the performance of a rapid soil health assessment tool developed by Landcare

Working with the Bass Coast, Westernport and South Gippsland Landcare groups, the first task involved the assessment of soils from a range of farms and reference sites. The soils were analyzed for a suite of key soil physicochemical properties, and the results compared to the results of Landcare's assessment of soil health, using their tool.

Task 2. Critically review the rapid soil health assessment tool developed by Landcare

The second task involved an assessment of the different parameters included in the rapid soil health assessment tool developed by Landcare. This task included an in-field assessment of the implementation of the tool by Landcare staff.

These tasks were undertaken in a number of phased activates, with associated milestones and completion dates (Table 1).

Table 1. Project activities, milestones/deliverables and timeline.

Project phase	Activity	Milestone/deliverable	Date
Phase 1: Site selection	Based on list of potential sites (to be provided by Landcare staff), identify (in conjunction with DSE EnSYM modellers) a short list of ~30+ sites for potential inclusion in the field phase of the project.	List of sites for soil sampling and soil health assessment to be used in Phase 2 of project.	September 10th 2010
Phase 2: Field sampling	Collect soil samples (4 per site) from 30 sites (2 sites at each of 15 farms) for analysis of key physicochemical properties. Soil sampling is to be undertaken in parallel with assessment of soil health using rapid soil assessment tool (by Landcare staff).	Survey undertaken and analyses performed	Mid-November 2010
Phase 3: Evaluation of results	Compare results of Landcare assessment of soil health (using rapid soil assessment tool) with soil physicochemical analysis. Make data available to DSE EnSym Modellers and participate in discussions relating to creation of Soil Health Gain Calculator	Draft report on analysis of results for inclusion in final report (Phase 4)	January 2011
Phase 4: Reporting	Final report	Written report	February 2011

Background – defining and quantifying soil health

We begin this report by providing some brief background information on soil health. In the interests of brevity, we restrict this section to: defining soil health, justification of measuring soil health, and the considerable challenges associated with the measurement of soil health. This is by no means a comprehensive review. For more detailed consideration of these and other issues, we recommend the following selected references:

Key reviews on soil health:

- Bennett L. T. Mele P.M. Annett S. Kasel S. (2010) Examining links between soil management, soil health, and public benefits in agricultural landscapes: an Australian perspective. *Applied Soil Ecology* **139:** 1-12.
- Doran J.W., Sarrantonio M., Liebig M.A. (1996). Soil Health and Sustainability. *Advanced in Agronomy.* **56:** 1-54.
- Doran J.W. Zeiss M.R. (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology*. **15:** 3-11.
- See also work on soil health undertaken by Victorian DPI: http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_home

Defining soil health

Soil health is a term that has been widely used in the context of agricultural production (Bennett *et al.* 2010; Kibblewhite *et al.* 2008). Soil quality and soil health are often used interchangeably; however, there are important differences between the concepts. Soil quality, reflects the soils capacity to produce agricultural goods, while soil health places greater emphasis on the current condition of the soil, reflecting management effects (Bennett *et al.* 2010; Kibblewhite *et al.* 2008); these two concepts are of course closely related. In the past there has been a strong emphasis placed on the chemical, and to a lesser extent, physical soil properties of soils, in terms of soil conservation. This approach, however, underestimates the importance of soil biological processes. This is an important omission as the soil biota are critically important in the cycling of nutrients and carbon in the soil (Jackson *et al.* 2008). The concept of soil health goes a long way to addressing this issue, with a more balanced emphasis placed on soil chemical, physical and biological properties. Consequently, soil health as a concept appeals more to farmers, as part of a holistic approach to soil management.

Key Points:

- Soil health refers to the ability of a soil to meet its range of ecosystem functions as appropriate to its environment.
- Soil health as a concept takes into consideration the chemical, physical and biological components of the soil.

The soil resource

There is no doubt that we need healthy soils. We rely upon soils to meet our food and fibre demands; they support critical ecosystem processes, such as nutrient cycling and enhance air and water quality; they contain, arguably, the largest terrestrial C stock on the planet; they play a major role in defining the composition and condition of vegetation, and other biotic communities; and they support significant industries; among many other important things (Bennett *et al*. 2010; Lal, 2004). Put simply, many of the ecosystem services upon which we rely, and a large part of the states economy, are in large part dependant upon soils and soil processes. It is therefore widely accepted, that if our soils are in a poor state there can be far reaching economic and environmental consequences.

While maintaining and enhancing soil health is essential, it is by no means assured. As the global population increases, so to will the demands placed upon our soils. To put this in context, the human population is projected to double in the next century, threatening to accelerate this degradation (Doran and Zeiss 2000). Furthermore, the UN has estimated that total food output must rise by 110% in the next 40 years to meet worldwide demand (FAO 2008). With the cost of fertilizers increasing dramatically, and dwindling global stocks of phosphorus (Cordell *et al.* 2009), it will become increasingly important to use our soils in a more sustainable manner. For example, a larger human population will have greater food and fibre requirements. This will place greater demands upon the soil resource, be it via agricultural intensification and/or the expansion of agricultural production into marginal or previously unfarmed lands.

The expansion of agricultural land is recognized as one of the most significant human impacts; however, this intensification and the use of fertilizers, irrigation and pesticides has contributed substantially to the increase in food production (Doran and Zeiss 2000). Our soil resources are critically important not only in the production of food, but also, in the maintenance of environmental health and quality. Taken together, our reliance upon, and the need to protect, our soils, has never been greater and is only likely to increase.

Fortunately, the importance of soil health is receiving increasing attention, especially at the policy and decision-making levels. While such recognition is important, it is equally important that we step back and consider what constitutes a healthy soil. In our own activities we have observed considerable uncertainty around not only what constitutes soil health, but also if and/or how it can (and should) be quantified. Despite these complexities, there remains the need to measure soil health. This is important in terms of taking stock of the soil resource and monitoring change (be it good or bad) following changes in land management. To this end there is a need to develop tools for quantifying soil health. Any such tools will have to deal with the tremendous spatiotemporal heterogeneity of soils; this is by no means a small challenge.

Key Points:

- To achieve sustainability, we need healthy soils.
- To meet the needs of an increasing global human population, both our reliance, and impacts, upon soils will increase.

- To manage soils in a sustainable way, we need to monitor their health.

Measuring soil health

To preserve agriculture for future generations, we must develop production systems that conserve and enhance soil quality, and soil health (Bennett *et al.* 2010; Doran *et al.* 1996; Doran and Zeiss 2000; Jackson *et al.* 2008). To achieve this goal it is necessary to have some measure of soil health so initial soil conditions can be characterized, and changes in conditions can be measured following changes in management and/or through time. Such a goal will require a relatively simple assessment of soil health that is reliable, sensitive enough to detect change within appropriate time scales for the information to be useful, and readily implemented in the field by a range of stakeholders, with varying levels of expertise and access to equipment and resources.

Rapid in field assessments have been successfully used to determine river and stream health, such as the index of stream condition streamside assessment protocol (Burger *et al.* 2010; Ladson *et al.* 1999). There is currently a lot of interest in developing a similar rapid soil health assessment tool, which is accessible to land managers, in terms of both time and money (Doran and Zeiss 2000; Jackson *et al.* 2008). It is therefore essential, that tools are developed in conjunction with end-users, to ensure that they are accessible and likely to be used to maximum effect.

While there is widespread agreement as to the need to measure soil health, there is relatively little agreement in the scientific community as to how best measure soil health. Nevertheless, there is a strong impetuous to move towards achieving this goal, especially with policy makers facing the need to make decisions now. To inform this process, there is a need for the impact of farm management practices on soil health to be determined.

A number of methods for the quantification of soil health have been proposed. These tools vary considerably in terms of the level of sampling intensity, expertise required, access to laboratory facilities, and so on. Again, this report does not provide a comprehensive review of these tools. Despite the number of approaches suggested for measuring health, most involve some in field sampling or assessment, the quantification of a range of soil chemical, biological and physical parameters, and assigning scores to each of the parameters. This is the approach undertaken in the rapid soil health assessment tool developed by Landcare (see Appendix 1).

In addition to rapid in field assessments of soil health (as outlined above), a number of "indicators" of soil health have been suggested. These include measures of soil biological activity, or the presence of specific functional groups of soil organisms. Commonly used examples include soil respiration, potentially mineralizable N (PMN), mycorrhizal colonization of roots, abundance of earthworms, soil microbial diversity, among many others. While not necessarily a measure of soil health, this indicator-based approach assumes that a "healthier" soil will have high levels of biological activity (e.g. respiration, PMN), more diverse or larger microbial communities (e.g. measures of microbial diversity and biomass), or greater representation of key functional groups (e.g. mycorrhizal colonization of roots, abundance of earthworms). The level of expertise required to perform these analyses varies widely, with quantification of soil respiration, PMN, mycorrhizal colonization of roots, microbial diversity and microbial biomass all requiring access to high level expertise and laboratory facilities and/or specialized equipment (e.g. for measuring soil respiration *in situ*). Nevertheless, where such techniques are available, they provide a valuable point of comparison to in field assessments of soil health.

Soil physicochemical properties are an important part of soil health. Measuring changes in key soil physicochemical properties is therefore a useful addition to soil health measurement tools. One advantage of these approaches is that soil can be readily sent to commercial laboratories for a wide array of soil tests, at relatively low cost. The results of these tests are, however, only as good as the soil sampling protocols upon which they rely. That is, if the soil sample analysed in not representative of the rest of the site, results will be of relatively little value or even misleading. Furthermore, sampling depth will also be important; for example, a soil may be healthy in the top 10 cm, but not at a lower depth. Similarly, sampling the same soil at different times of year may yield very different results. There is therefore, a need for careful attention to soil sampling techniques, and interpretation of findings and subsequent decision making processes. To this end, inadequate and/or unrepresentative sampling is likely to be one of the most important impediments to rapid soil health assessment tools.

Key Points:

- Measuring soil health is a complicated challenge, with many different approaches suggested.
- Methods for measuring soil health on a large scale will need to be readily implemented in the field, and sensitive enough to detect change within appropriate time scales for the information to be useful.
- Given the tremendous spatiotemporal variation in soils and soil properties, sampling regimes need to be very carefully designed in any assessment of soil heath.

Our approach: measuring soil health in the field

The main objective of this project was to assess and review the performance of the rapid soil health assessment tool developed by Landcare. To do this, two tasks were undertaken. We now outline our approach to completing these two tasks, and results of these activities.

Task 1. Methods

Task 1. Assess the performance of a rapid soil health assessment tool developed by Landcare.

Working with the Bass Coast, Westernport and South Gippsland, Landcare groups, the first task involved the assessment of soils from a range of farms and reference sites. The soils were analyzed for a suite of key soil physicochemical properties, and the results compared to the results of Landcare's assessment of soil health, using their tool.

Site selection

Field sites in the Port Phillip Bay catchment area were selected in consultation with Landcare project officers, with the aid of the desktop modeling program, EnSym. EnSym was used in collaboration with DSE, to select specific sites using site polygons and aerial maps. Sites were selected with consideration of the Northcote soil classifications (Figure 1), the availability of soil management history, grazing regime, and enterprise type (data provided by Landcare and land holders). Additional geographic characteristics such as slope, aspect, mean annual rainfall, mean annual temperature and bioregion, were also included in the site selection decision-making process. More than 70 potential sites were identified. From this list of sites, 40 sites were selected in conjunction with Landcare staff to ensure that the sites selected were representative of land use and land management practices, across the sampling region. The final sites included in the study are given in Figure 2. Soil types across the region are given in Figure 1. Soil types included in this project are given in Figure 3. Rainfall across the region sampled is given in Figure 4. Summary information for each site is given in Table 2.

Key Points:

- The EnSym modeling platform, along with data from Landcare, was used to identify >70 potential field sites.
- Working with Landcare officers, a final pool of 40 sites was selected for inclusion in this project.
- Important factors considered in final site selection included soil type, access to soil management records, and other geographic variables, to ensure the target region was well covered.

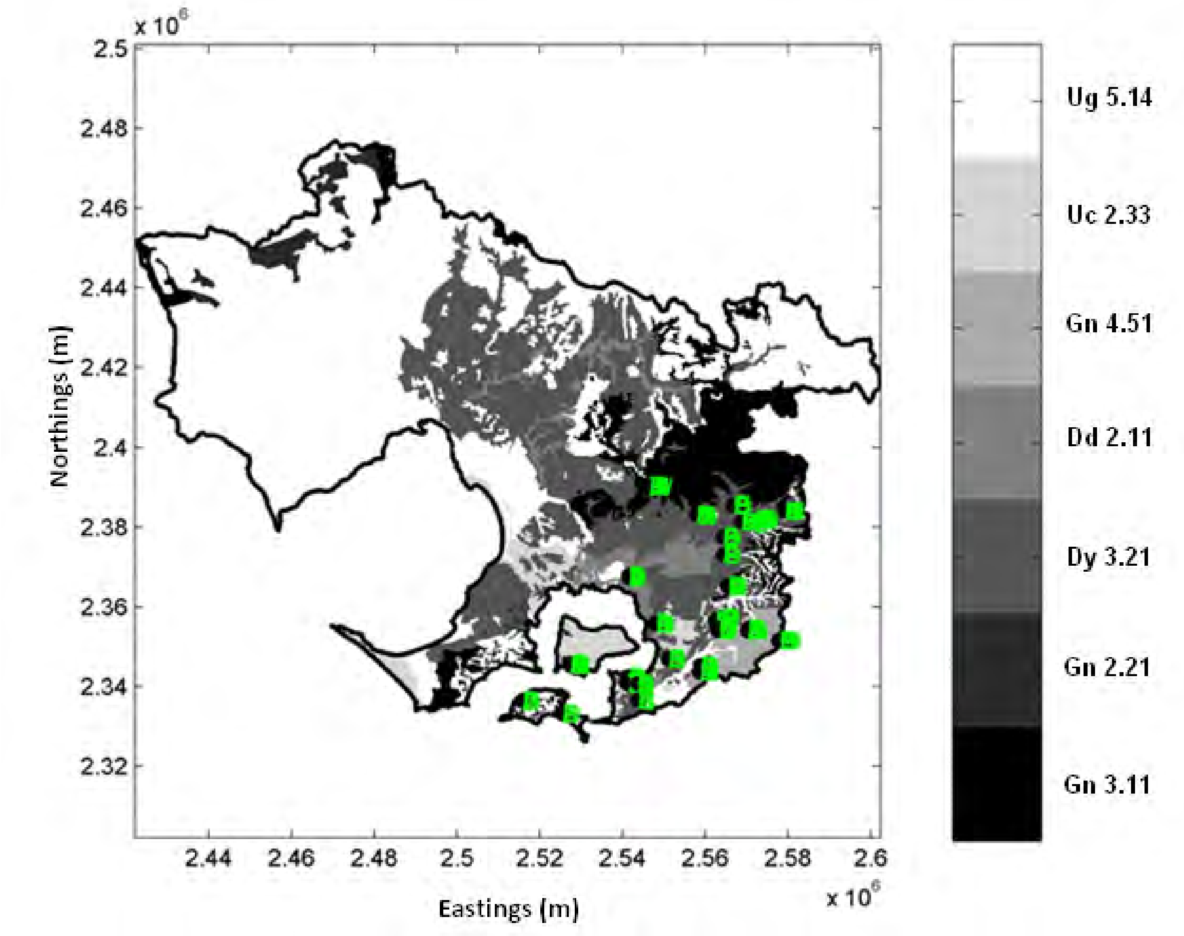

Figure 1. Northcote soil classifications in the Port Phillip Bay catchment area, with sites included in this project indicated (shown in green).

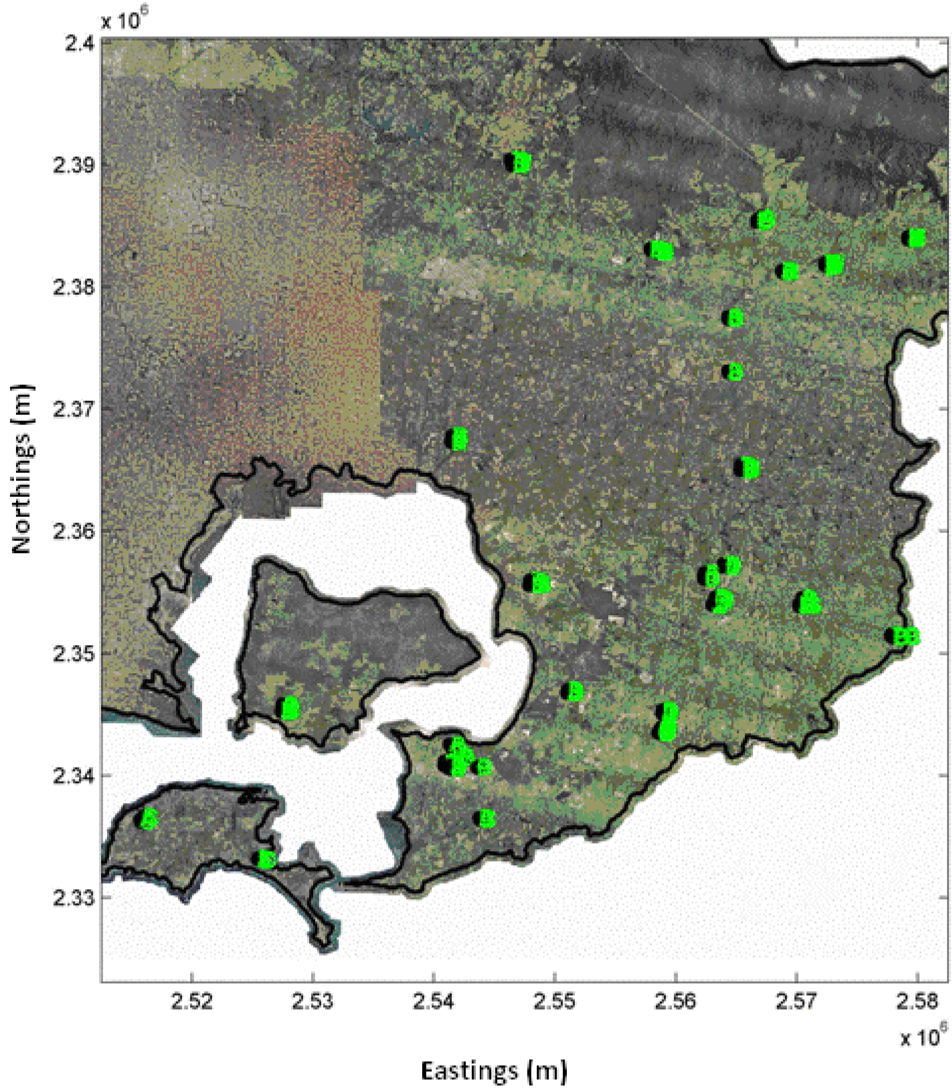

Figure 2. Aerial photograph of Port Phillip Bay catchment area, with sites included in this project indicated (shown in green).

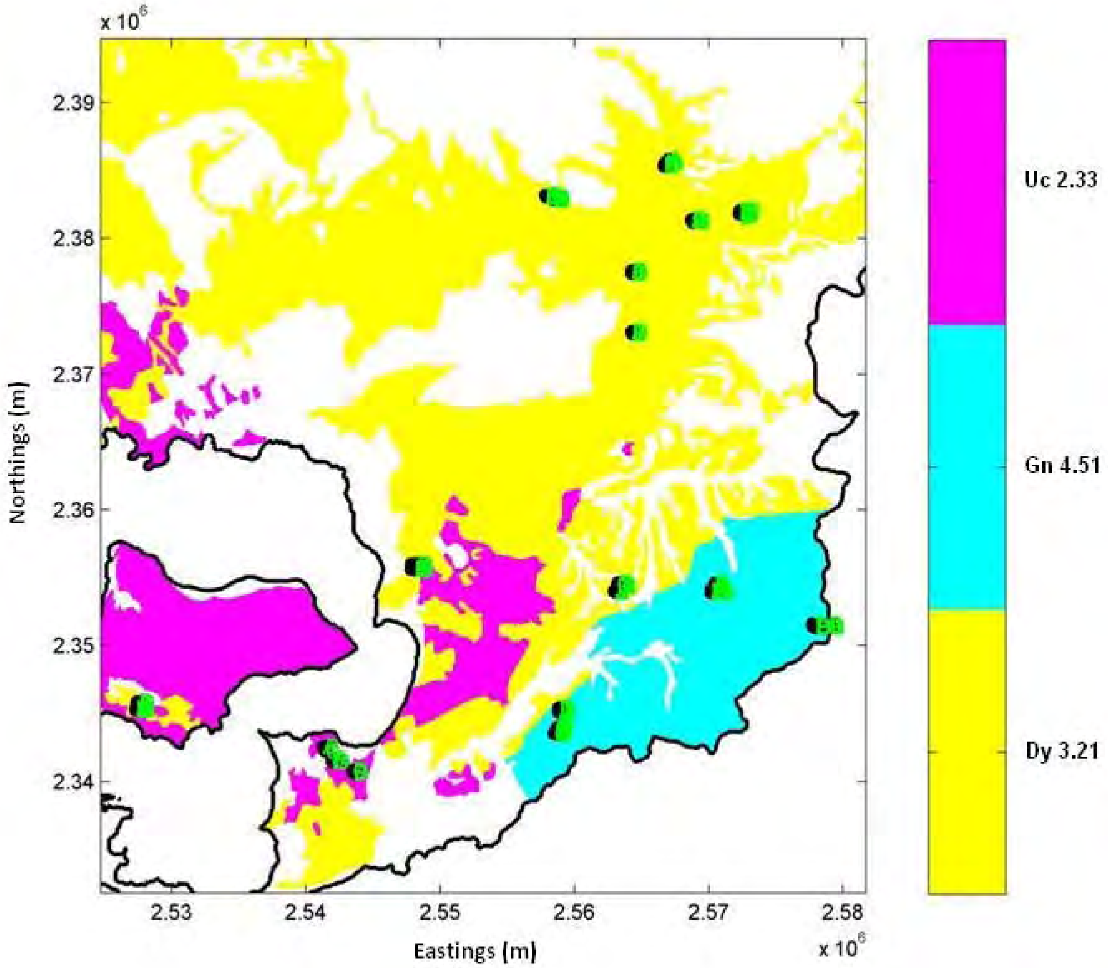

Figure 3. Northcote soil classifications in the Port Phillip Bay catchment area of soil types used in this project, with sites included in this project indicated (shown in green).

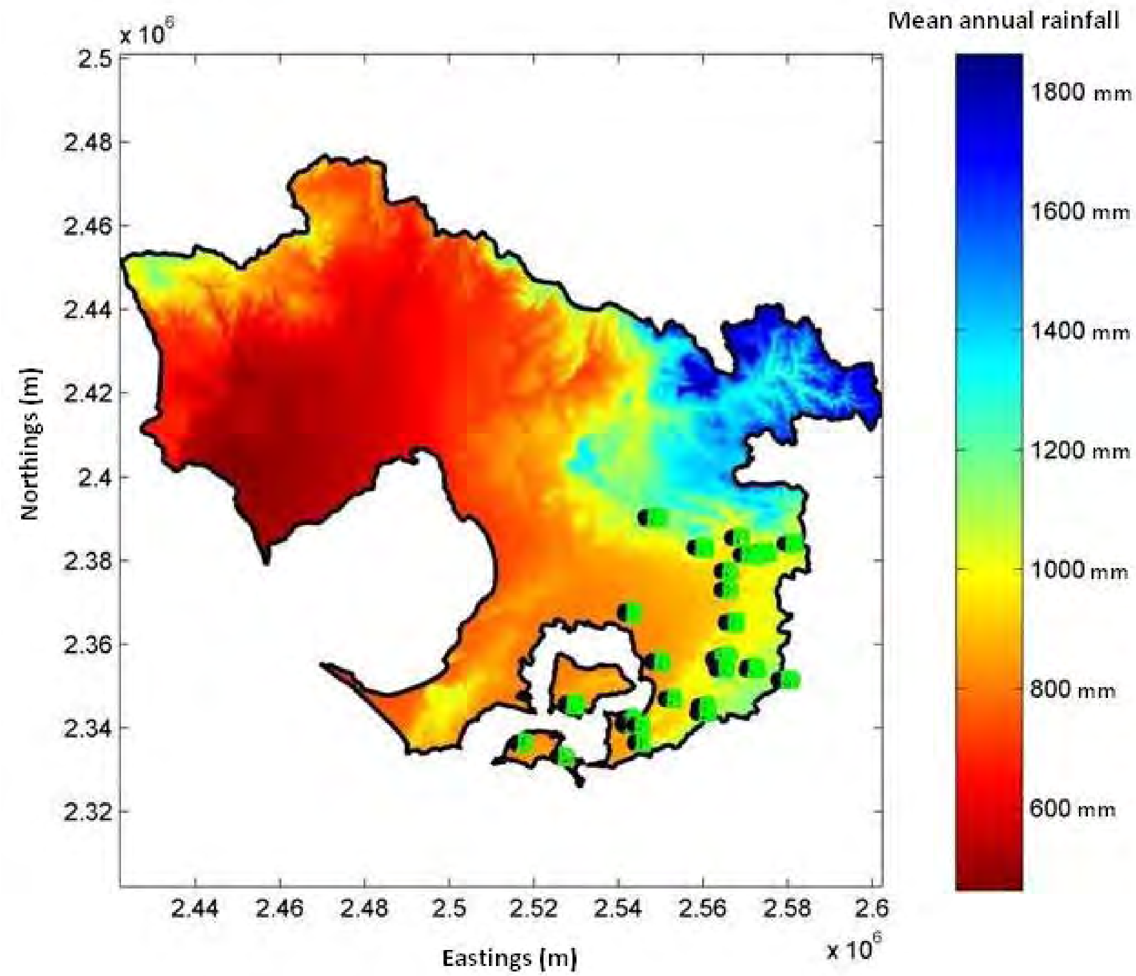

Figure 4. Mean annual rainfall in the Port Phillip Bay, with sites included in this project indicated (shown in green).

Table 1. Summary data for sites included in this project.

Site	Site Id	Network	Site location	Soil code	Texture	Enterprise type	Land-use
1	TUC 001	Bass Coast	Grantville	Uc 2.33	Loam	Beef	Grazed
2	TUC 002	Bass Coast	Grantville	Uc 2.33	Clay Loam	Beef	Grazed
3	STO 001	Bass Coast	Kongwak	Gn 3.91	Loam	Beef	Grazed
4	STO 002	Bass Coast	Kongwak	Gn 3.91	Loam	Beef	Grazed
5	CLE 001	Bass Coast	Surf Beach	Ug 5.14	Loam	Beef & sheep	Grazed
6	CLE 002	Bass Coast	Surf Beach	Ug 5.14	Loam	Beef & sheep	Grazed
7	MIT 001	South Gippsland	Nyora	Dy 3.21	Loam	Dairy	Grazed
8	MIT 002	South Gippsland	Nyora	Dy 3.21	Loam	Dairy	Grazed
9	MIT 003	South Gippsland	Nyora	Dy 3.21	Clay loam		Revegetation
10	MIT 004	South Gippsland	Nyora	Dy 3.21	Clay loam		Remnant
11	RON 001	Westernport	Jindivick	Gn 3.11	Loam	Dairy	Grazed
12	RON 002	Westernport	Jindivick	Gn 3.11	Loam	Dairy	Grazed
13	ARM 001	Westernport	Labertouche	Dy 3.21	Loam	Beef	Grazed
14	ARM 002	Westernport	Labertouche	Dy 3.21	Loam		Revegetation
15	ARM 003	Westernport	Labertouche	Dy 3.21	Clay		Remnant
16	CUN 001	Westernport	Tynong North	Dy 3.21	Loam	Beef	Grazed
17	CUN 002	Westernport	Tynong North	Dy 3.21	Loam	Beef	Grazed
18	JEN 001	Bass Coast	French Island	Dy 3.21	Clay loam	Beef	Grazed
19	JEN 002	Bass Coast	French Island	Dy 3.21	Clay loam		Remnant
20	JEN 003	Bass Coast	French Island	Dy 3.21	Clay loam	Beef	Grazed
21	BAR 001	South Gippsland	Loch	Gn 4.51	Clay loam	Dairy	Grazed
22	BAR 002	South Gippsland	Loch	Gn 4.51	Clay loam	Dairy	Grazed
23	BOY 001	South Gippsland	Strzelecki	Gn 4.51	Clay loam	Beef	Grazed
24	BOY 002	South Gippsland	Strzelecki	Gn 4.51	Clay loam	Beef	Grazed
25	FRA 001	Westernport	Pakenham Upper	Gn 3.11	Clay loam	Beef	Grazed
26	FRA 002	Westernport	Pakenham Upper	Gn 3.11	Clay loam		Remnant
27	END 001	Westernport	Labertouche	Dy 3.21	Clay loam	Beef	Grazed
28	END 002	Westernport	Labertouche	Dy 3.21	Clay loam	Beef	Grazed
29	END 003	Westernport	Labertouche	Dy 3.21	Clay		Remnant
30	AND 001	Westernport	Bunyip	Dy 3.21	Clay	Beef	Grazed
31	AND 002	Westernport	Bunyip	Dy 3.21	Clay loam	Beef	Grazed
32	MUR 001	Westernport	Longwarry Nth	Dy 3.21	Clay	Dairy	Grazed
33	MUR 002	Westernport	Longwarry Nth	Dy 3.21	Clay loam	Dairy	Grazed
34	NIE 001	Westernport	Iona	Dy 3.21	Clay loam	Dairy	Grazed
35	NIE 002	Westernport	Iona	Dy 3.21	Clay loam	Dairy	Grazed
36	MAT 001	Bass Coast	Glen Alvie	Gn 3.91	Clay	Dairy	Grazed
37	MAT 002	Bass Coast	Glen Alvie	Gn 3.91	Clay	Dairy	Grazed
38	PAT 001	South Gippsland	Lang Lang	Dy 3.21	Clay	Dairy	Grazed
39	PAT 002	South Gippsland	Lang Lang	Dy 3.21	Clay		Remnant
40	PAT 003	South Gippsland	Lang Lang	Dy 3.21	Clay	Dairy	Grazed

To identify changes in soil health, we attempted to identify farms with paddocks with contrasting management. It was envisaged that this would allow differences in soil health to be identified, without the confounding effects of changes in soil type, of which there are six in the region included in this study. While we were able to identify 17 farms with 2 or more paddocks with apparently contrasting management, there was very little consistency in the type of management data recorded for each site (due to different manager at every farm) and/or access to these data. This made it very difficult to classify sites on the basis of management intensity. Nevertheless, some insights are to be gained from making pairwise comparisons between the sites we were able to identify (see results).

Field sampling

Soil health was assessed at all of the field sites in October to November, 2010. During this time, unseasonably high rainfalls were experienced. It is therefore important to consider the results of these activities in the context of a very wet Autumn. It will also be important to take this into account in any future assessment of soil health at these sites. Soil health was monitored in two ways - the Landcare rapid soil health assessment, using their tool, and a detailed survey of soil properties.

Field sampling: Landcare rapid soil health assessment

At each site, soil health was quantified by Landcare staff, using the rapid soil health tool developed by Landcare (see Appendix 1). Briefly, in the centre of each site (avoiding watering points, gates and feeding areas) a small soil pit measuring 20 cm wide, 20 cm long and 40 cm deep, was dug. The following soil properties were then recorded and assigned a score as per the soil health rapid assessment tool: Depth of organic matter (visual), Leaf colour (visual), Root depth (visual), Macro-life (count), Earthworm count (count), Root development (visual), Soil structure (visual), Aggregate stability (in field test), Soil compaction (in field measurement). The following properties were taken from soil tests, % Organic matter, soil pH and Cation Exchange Capacity

(CEC). Pasture condition was assessed at each site by recording the presence of productive pasture species, bare ground or litter, every meter along a 60 m transect, which was centred on the soil pit (see above). Assessment of soil health was undertaken at each site by one of three different Landcare officers. This provided an important opportunity to assess the implementation of the tool. See Task 2.

Key Points:

At each of the sites sampled a Landcare field officer measured soil health using the soil health rapid assessment tool.

Field sampling: Detailed analysis of soil physical, chemical and biological properties

We undertook a detailed soil survey of soil physical, chemical and biological properties at each of the sites. The approach used builds of a number of recent research projects we have undertaken across the Victorian agricultural sector, with various industry organizations and state and federal government agencies (Cavagnaro and Martin 2011; Mosse *et al.* 2010; Reich *et al.* 2009). At each of the sites soil physical, chemical and biological properties, and vegetation properties were measured. At each site, a 20m x 20m plot was established in the center of the site (Figure 5). This sampling area, which was centered on the soil pit dug as part of the Landcare assessment of soil health (see above), was divided into four 10m x 10m plots. Within each plot soil and vegetation properties were quantified.

Key Points:

At each site four sampling plots, centered on the point where Landcare assessed soil health, were established for soil and vegetation analysis.

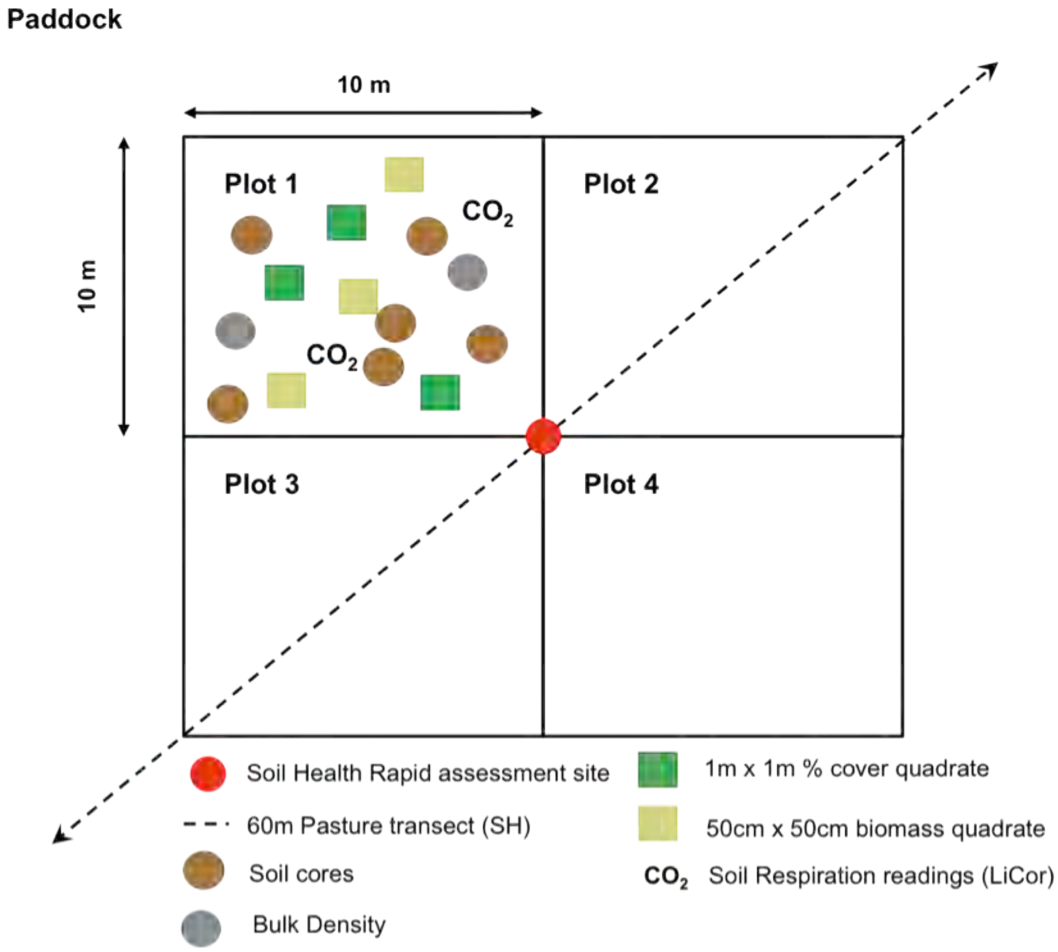

Figure 5. In site sampling regime with 20m x 20m sampling area, divided into 4 (10m x 10m) plots. Within each plot soil and vegetation samples were taken. Plots 2-4 were sampled as for in Plot 1. N.B. respiration was only measured at sites on soil type Dy3.21 (see text and Table 2). Diagram not drawn to scale.

Vegetation and soil analysis

Within each 10m X 10m plot three randomly placed 1 m X 1 m sub-plots were established (see Figure 5). Within each of these plots the percentage of plant cover was determined by visual assessment (referred to as percent cover hereafter) following Burger *et al*. (2010). The above-ground biomass in each of these sub-plots was then clipped (at the soil surface) from a 50 cm X 50 cm area. This biomass was stored in paper bags until return to the laboratory, and then dried at 60^{o}C for determination of biomass dry weight.

Bulk density, a measure of soil compaction, was measured in duplicate within each 10 X 10 m plot (see Figure 5). Briefly, a metal core of known volume was gently tapped into the soil centered on a depth of 10 cm (i.e. the mid-point of the 0-20 cm soil layer) (following, Minoshima *et al.* 2007). Upon return to the laboratory the soil was removed from the cores, weighed, and divided into two sub-samples. The first sub-sample was used to determine soil gravimetric moisture content following drying at 105°C for 48 hrs. Roots were extracted from the second sub-sample by wet sieving (Cavagnaro *et al.* 2006). The extracted roots were weighed and divided into two sub-samples. The first sub-sample was dried for 48 hours at 60°C, and root biomass (dry) per g dry soil determined. The second root sub-sample was used for determination of mycorrhizal colonization of roots (see below).

Soils were sampled as follows. Within each 10 m X 10 m plot six soil cores from the 0-20 cm soil layer were taken using a (10 cm diameter) auger (see Figure 5) (Burger *et al.* 2010; Cavagnaro and Martin 2011). The six cores from each plot were combined and mixed in the field, thereby providing a composite soil sample from each of the four plots at each site. The composite soil samples were placed in an air-tight bags and immediately stored at 4 °C, to minimize biological activity (Cavagnaro *et al.* 2006), and returned to the laboratory for analysis.

Upon return to the laboratory, soil samples were sieved (2.5 mm) to remove sticks, coarse roots and rocks (Burger *et al.* 2010). Gravimetric moisture was determined after drying approximately 50 g moist soil samples at 105^{o}C for 48 h. Triplicate soil samples (30 g moist soil) were taken, extracted with 2M KCl, and inorganic N content determined colorimetrically using a modification of Miranda *et al.* (2001) for NO_3^- (plus NO_2^-) and Forster (1995) for NH_4^+. The soil was further sub-sampled for quantification of potentially mineralizable nitrogen (PMN) (see below).

The remaining soil was then sent to an external commercial laboratory (EAL) for analysis of a suite of physicochemical properties (Appendix 2). This approach was selected for the following reasons:

1. A comprehensive suite of soil properties are measured;
2. Should farmers wish to re-sample and analyze their soil in the future, it provides them with an opportunity to send samples to the same commercial lab, which will allow for comparisons of change;
3. Should there be a desire to modify the soil health tool to include lab based measures of soil properties, this approach ensures consistency as farmers have ready access to such commercial labs; and
4. In past projects we have found the results from the commercial lab to be reliable and a useful indicator of changes in soil properties (Cavagnaro and Martin 2011; Mosse *et al.* 2010).

Following commencement of field sampling we became aware of a desire to collected additional information on soil C. Consequently, additional measures of soil C (labile C and %TOC) were included in the analysis.

While a wide range of soil properties were measured, not all were included in our analysis of the data. Our approach was to focus on a number of soil properties which we considered to be indicative of key soil processes (i.e. desirable in a “healthy soil”). While other soil properties could have been selected, those presented here have been found to be useful in previous projects (see references cited above). These parameters, and relevant background information (in brief) were:

Plant-available P (Colwell): This test estimates the availability of P in the soil to plants. Various methods for measuring plant-available P have been developed (Olsen, Bray, Morgan, etc). The Colwell test is widely used in the Australian context.

Cation exchange capacity (CEC): The CEC of a soil is a measure of its capacity hold and exchange cations. It is calculated based on the sum of individual cations displaced from the soil. This is estimated by forcibly displacing the exchangeable ions, such as sodium, calcium, magnesium and potassium already in the soil, with a strongly absorbed cation retained by the soil. A low CEC indicates the soil has a low resistance to changes in soil chemistry (Carter and Gregorich 2008; Hazelton and Murphy 2010.).

Total Carbon: Total C is a measure of the total amount of carbon in the soil. Total C is measured using a range of methods, the most widely accepted being the dry combustion method (as used here) (Burger *et al.* 2010; Minoshima *et al.* 2007).

Total Nitrogen: Total nitrogen is a measure of the total amount of nitrogen present in soil. Forms of N in the soil can be both organic and inorganic in form. Total N is measured by dry combustion along with total C (Hazelton and Murphy 2010.; Rayment and Lyons 2011).

Carbon:nitrogen ratio: The C:N ratio gives an indication of the relative amounts of total carbon to that of total nitrogen in the soil. The C:N ratio is derived by dividing the percentage of organic carbon by the percentage of total nitrogen in the soil (Hazelton and Murphy 2010.; Rayment and Lyons 2011). A high C:N ratio, implies the accumulation of organic matter is occurring at a faster rate than decomposition (CSIRO 2006). Changes in C:N ratio can also have a strong impact on soil microbial communities, and plant N uptake.

Labile Carbon: The residence time of different forms of C vary greatly, with recalcitrant pools of C remaining in the soil for a long time and labile forms of

C being turned over more rapidly. Labile C, also known as active C, includes pools of C such as simple carbohydrates which are utilized by soil microbes.

Nitrate (NO_3^-): Nitrate is readily available to plants. The turn over of nitrate in the soil can be rapid. Nitrate is of particular interest as it can be readily leached through the soil below the root zone, and under wet conditions can be converted (via denitrification) into the greenhouse gas N_2O (Hazelton and Murphy 2010.; Jackson *et al.* 2008; Rayment and Lyons 2011).

Ammonium (NH_4^+): Ammonium is also a mineral form of nitrogen that can be used by plants. It is often absorbed onto clay and silt minerals and soil levels are generally low (Rayment and Lyons 2011). The turnover of ammonium in the soil is extremely dynamic, with its conversion to nitrate (via nitrification) being an important soil process (Jackson *et al.* 2008).

Potentially mineralizable N (PMN): The mineralization of N, that is, the conversion form an organic form to an inorganic form, is an important soil process. The rate at which the process occurs, which can be determined using an anaerobic incubation over 7 days (CSIRO 2006), can be used as a measure of soil biological activity.

Potassium (ammonium acetate test): Potassium is a readily available to plants and is held in its exchangeable form. Ammonium acetate extractions are used to measure the soluble plus exchangeable potassium pools in soils. The potassium ions are held in form by the negative charge on the surface of soil organic matter and are thought to be a good indicator of the amount of potassium available for plant development (Rayment and Lyons 2011).

Key Points:

- Soils were sampled from the plots established at each site for later analysis of important properties.
- Vegetation properties were measured in each of the plots at each site.

Measures of soil biological activity

As noted above, a number of key biological processes have been identified as indicators of soil health. A selection of these methods were therefore included in this study.

Potentially mineralizable nitrogen (PMN)

Background: The PMN assay measures the rate of nitrogen mineralization (or ammonification; production of NH_4^+ from organic N) under ideal conditions (anoxic, saturated soil). As such, it represents the maximum capacity of nitrogen mineralization in the soil at the time of analysis. Differences in rates of PMN can be attributed to the size of ammonifying bacteria and/or archea populations present in the soil along with substrate (organic C and N) availability.

Method: For the PMN assay, triplicate 7 g fresh soil sub-samples were weighed into 50 mL tubes, to which 10 mL of reverse osmosis water was added. Nitrogen gas was pumped into the head space and tubes sealed with a stopper to maintain anaerobic conditions, thereby inhibiting nitrification (an aerobic process). Samples were incubated for 7 days at 37°C. On the seventh day inorganic nitrogen was extracted by addition of 10 mL 4M KCl, followed by analysis (see above).

Arbuscular mycorrhizas (AM)

Background: Most terrestrial plant species form arbuscular mycorrhizas (AM) with a specialized group of near ubiquitous soil fungi (Smith and Read 2008). AM can significantly increase plant acquisition of (especially) P, but also N and other nutrients (Cavagnaro 2008; Kothari *et al.* 1990; Marschner and Dell 1994; Smith *et al.* 2003; Tanaka and Yano 2005). AM also have the potential to play an important role in reducing N and P loss via leaching (Asghari *et al.* 2005; Entry and Sojka 2007). AM are also sensitive to excessive nutrient application, disturbance (e.g. tillage and grazing) and the use of fungicides and other pesticides (Cavagnaro and Martin 2011; Smith and Read 2008).

Method: Mycorrhizal colonization, a measure of the extent to which roots are colonized by AM fungi was measured, as follows. Plant roots were cleared with 10% KOH (W/V) for 3 days at room temperature and stained with Trypan blue using a modification of the method of Phillips and Hayman (1970), omitting phenol from the reagents. Roots were observed at × 40 magnification and colonization of roots by AM fungi determined using the line intersect method (Giovannetti and Mosse 1980). It is important to note that it was not possible to distinguish between the roots of different plants species, therefore, the colonization data reported here are from a composite root sample, potentially made up of a number of plant species, which may be constitutively mycorrhizal or non-mycorrhizal, for each 10 m X 10 m plot. We do, however, note that the dominant plant species at the sites sampled are known to form AM.

Soil respiration

Background: Soil respiration refers to the release of carbon from the soil surface in the form of carbon dioxide. As such, it is a measure of the biological activity in the soil (Cavagnaro *et al.* 2008; Jackson *et al.* 2008). The measurement of soil respiration *in situ* requires the use of specialized equipment (e.g. LiCor 6400 with soil respiration chamber).

Method: Soil CO_2 efflux was measured *in situ* using a LI-6400 fitted with a soil respiration chamber (LI-COR Biosciences) at sites on soil type Dy3.21 (See Table 2). Due to the excessive rainfall, it was not possible to take reliable (on indeed at some sites, any) soil respiration measurements. Consequently, this measure of soil biological activity is not considered further, although we do recognize its usefulness where measurements are possible, and therefore, retain reference to it in this report.

Key Points:

- Soil biological activity was measured in a number of ways at all sites as an indication of soil health.

Data presentation and interpretation

Data collected in this project are reported on in a number of ways:

Summary data

Results of the Landcare rapid assessment of soil health results are presented as means by site. More detailed within site score data, on a site-by-site basis, is given in Appendix 2.

For each site, the number of (selected, see below) soil properties that were within their desirable range was calculated. Desirable ranges, which take into account differences in soil textural classes, were based upon those provided by the analytical laboratory. For plant available P, total N, CEC, C:N ratio, potassium, nitrate and ammonium, values which fell within 50% either side of the desirable range were considered to be satisfactory. Those outside this range were considered to be unsatisfactory. In the case of labile C and total C, results were considered to be satisfactory if they were greater than 50% of the desirable level. This approach recognises that it is unlikely that having a very high result from some soil properties is undesirable, e.g. soil C. Finally, for soil properties where there is not agreed desirable level (e.g. PMN), sites falling above the median value (from all sites in this study) were considered to be “healthier” than those falling below the median.

Measures of general soil biological activity, including PMN and mycorrhizal colonization of roots, are presented as site means.

Comparing measures of soil health

To assess its performance, scores from the rapid soil health assessment tool developed by Landcare, were compared to the number of key soil properties measured in the detailed soil analysis found to fall within the desirable range (see above). This relationship was further explored by comparing results from only those sites that were on the most common soil type included in this study.

Management impacts on soil health

During the site selection process a number of paired sites (i.e. on same farms) with different management histories were identified in conjunction with Landcare staff. To assess the performance of the soil health rapid assessment tool developed by Landcare, soil health scores and soil properties were compared between these pairs of sites. The aim was to determine whether or not soil health differed (by the measures used here) where a difference may be anticipated (e.g. more intensive versus less intensive agricultural management). It is important to note that relatively few sites were identified where there were large differences in management; however, some examples were found and are considered here.

Key Points:

- Soil health scores and other physicochemical properties are presented in summary form.
- Performance of the rapid soil health assessment tool developed by Landcare was undertaken by comparing it with results of key soil physicochemical and biological properties.
- The impact of site management on soil health was considered in a sub-set of paired sites.

Task 1. Results

Summary data

The Landcare rapid soil health assessment scores range from 34-73, with a mean of 49 across all sites (Figure 6).

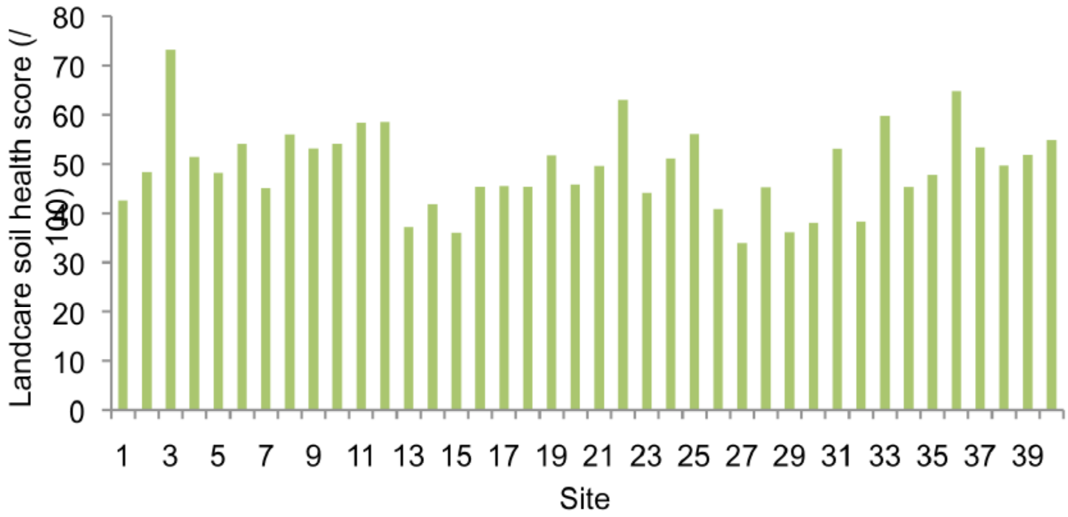

Figure 6. Rapid soil health assessment scores for 40 Landcare sites.

In the detailed soil survey and analysis, the number of soil properties considered to be in the desirable range (Figure 7) ranged from 0 to 8 (out of a possible maximum score of 10), with a mean of 4 across all sites.

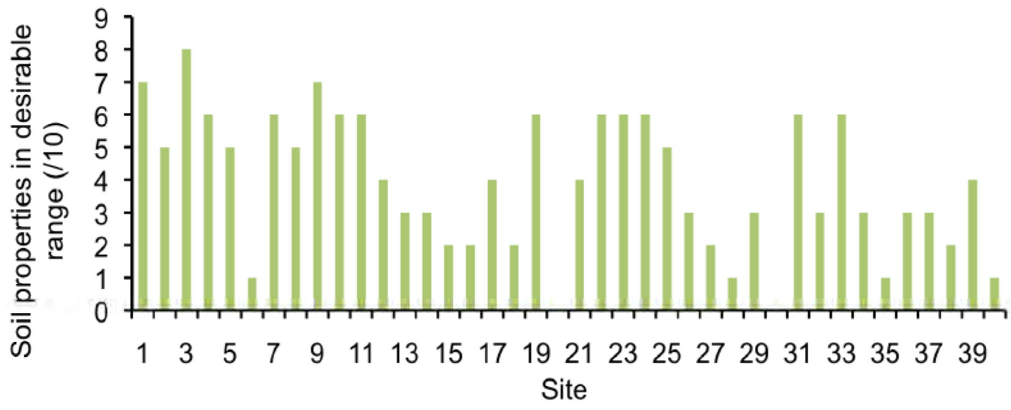

Figure 7. Number of soil properties within the desirable range for 40 Landcare sites.

The PMN at the sites (Figure 8) ranged from 2.5 to 35 (ug NO_3^-/g), with a mean of 13.6 (ug NO_3^-/g) across all sites.

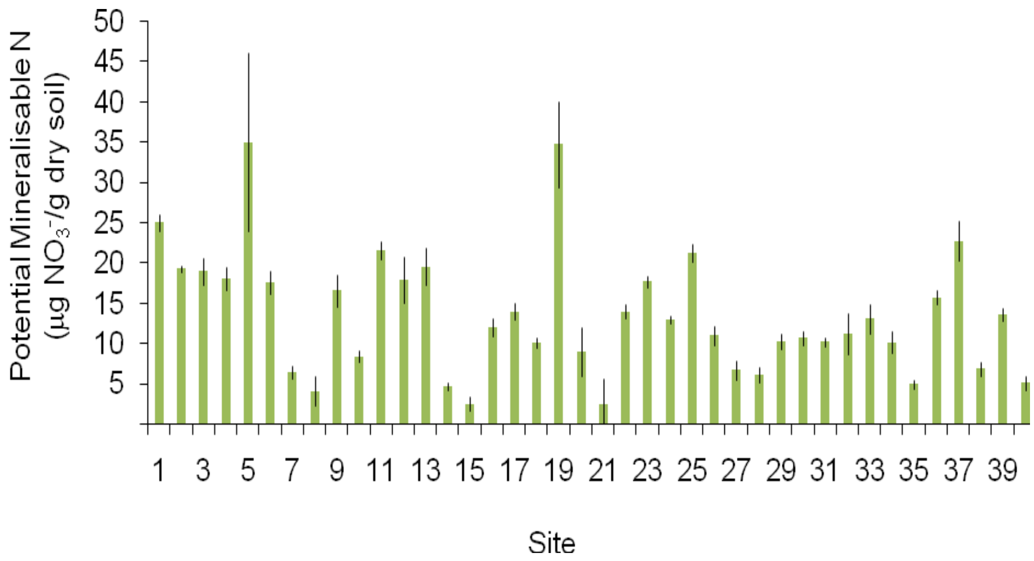

Figure 8. Potential mineralizable N in soils from 40 Landcare sites. Values are site means ± SE, n=4.

Levels of mycorrhizal colonization were generally high across all sites (Figure 9) with levels ranging from 39 to 77%, and with a mean of 57% across all sites.

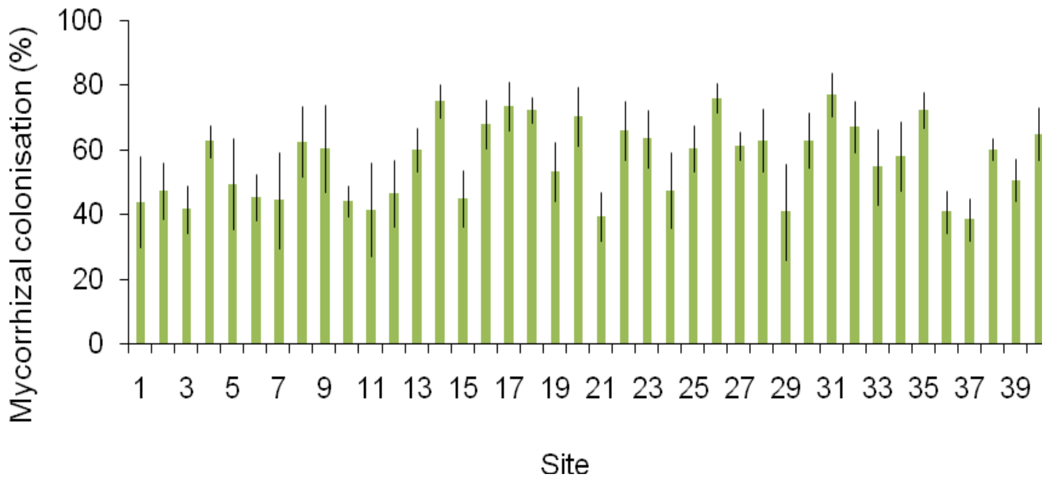

Figure 9. Mycorrhizal colonization of roots in soils from 40 Landcare sites. Values are site means ± SE, n=4.

Levels of soil C (% total soil C, by dry combustion) (Figure 10) ranged from 1.2 to 6.3%, with an across site mean of 3%.

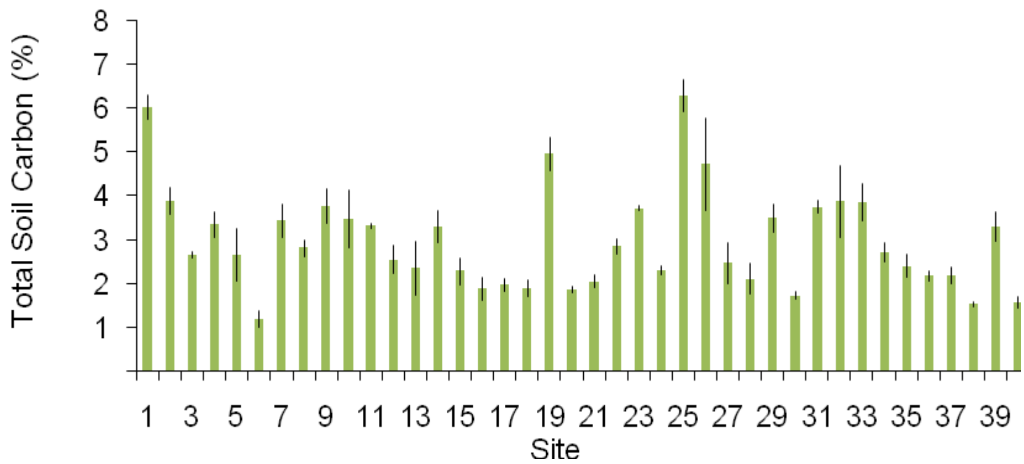

Figure10. Mean total soil carbon (%) in soils from 40 Landcare sites. Values are site means ± SE, n=4.

At the request of Landcare, additional measures of soil C were included. These include labile C (Figure 11) and total organic C (Figure 12). For Labile C, site means ranged from 0.2% to 1.9%, with an across site mean of 0.5%. In the case of total organic C, site means ranged from 1.1% to 5.7%, with an across site mean of 2.8%.

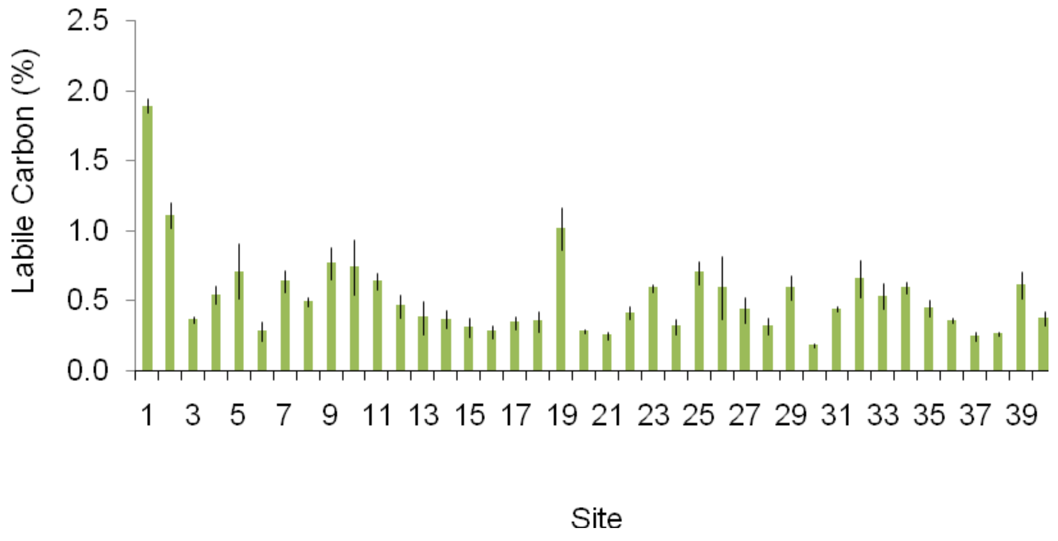

Figure 11. Mean labile soil carbon (%) in soils from 40 Landcare sites. Values are site means ± SE, n=4.

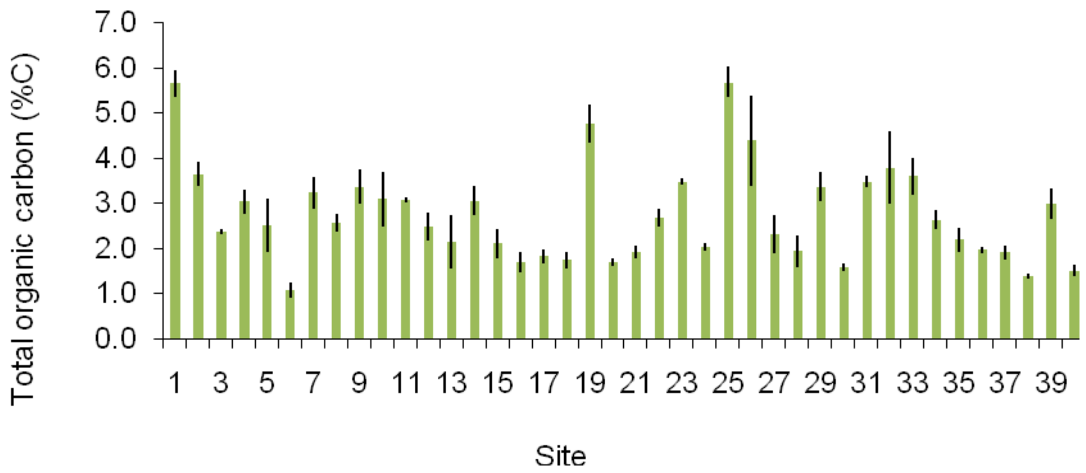

Figure12. Mean total soil organic carbon (%) in soils from 40 Landcare sites. Values are site means ± SE, n=4.

Key Points:

- Soil health scores, and the number of physicochemical properties considered to be in the desirable range varied widely across the sites sampled.
- Measures of soil biological activity, (PMN and mycorrhizal colonization of roots) were generally moderate to high.

Comparing methods of measuring soil health

There was a positive correlation between the Landcare soil health rapid assessment score and the number of soil properties considered to be in the desirable range by site (Figure 13). This positive, albeit relatively weak, correlation provides some indication of agreement between the two approaches to assessing soil health.

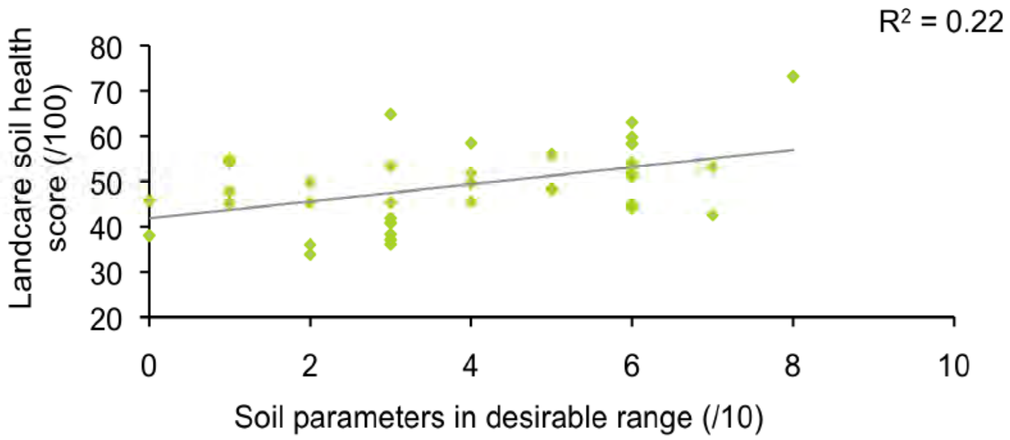

Figure 13. Relationship between rapid soil health assessment score and number of soil properties considered to be within desirable range, in soils from 40 Landcare sites.

In an effort to investigate the impacts of land management on soil health a number of sites with paddock trees were included in the analysis. The condition and management of these sites varied considerably. Therefore, the data presented in Figure 13 are presented again with these data omitted (Figure 14). This slightly improved the strength of the relationship between the two measures of soil health considered here.

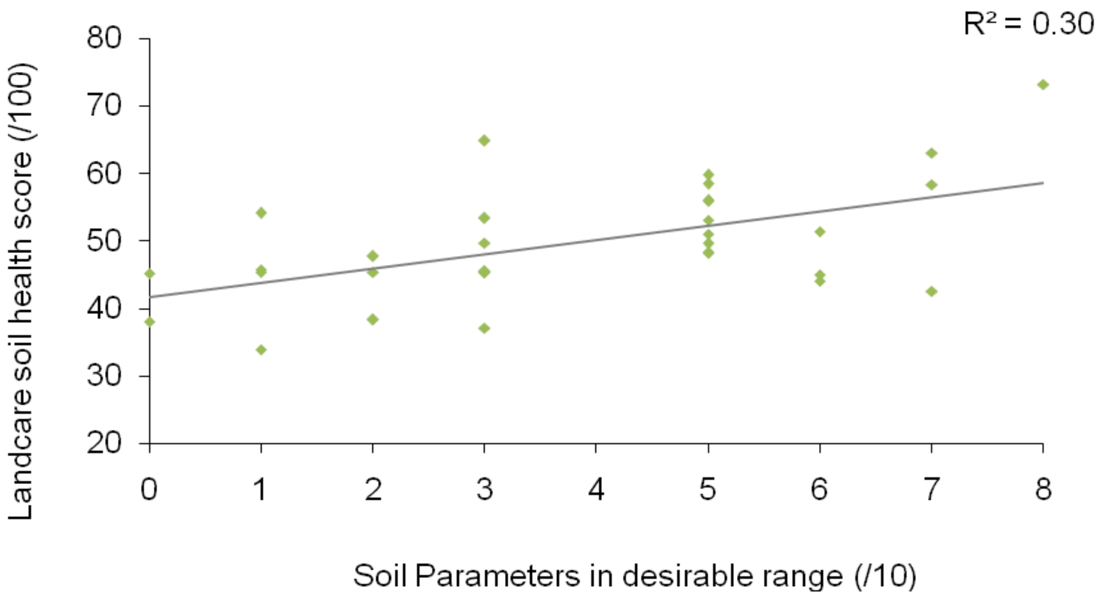

Figure 14. Relationship between rapid soil health assessment score and number of soil properties considered to be within desirable range, with sites containing trees omitted.

In light of the considerable variation in soil type across the region sampled, a sub-set of sites on the most frequently sampled soil type were considered separate from all other sites. Again, there is a weak, positive correlation between the Landcare soil health rapid assessment score and the number of soil properties considered to be in the desirable range by site (Figure 15).

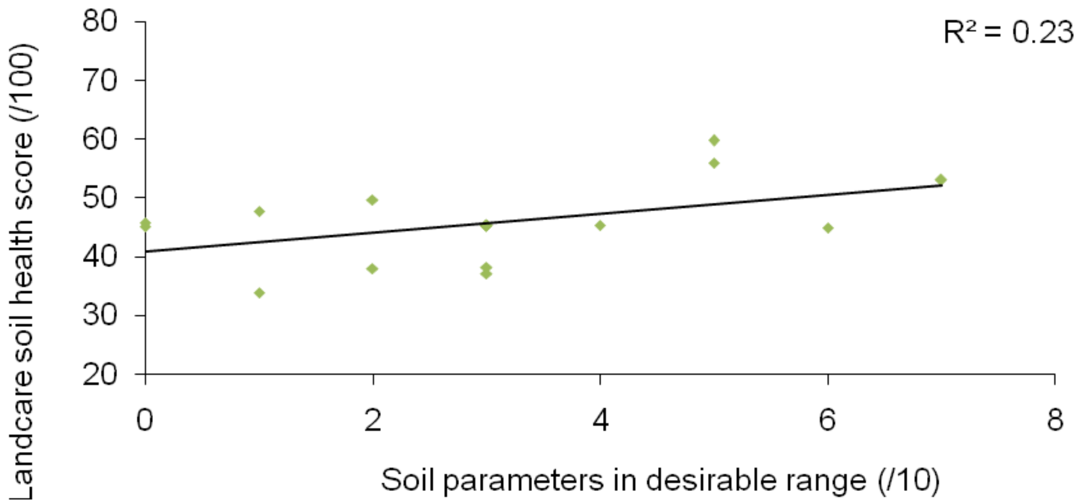

Figure 15. Relationship between rapid soil health assessment score and number of soil properties considered to be within desirable range, for the soil type Dy3.21, excluding sites with trees. Values are means +/-SE .

Key Points:

- There was a positive, albeit it relatively weak, relationship between soil health scores and the number of physicochemical properties falling into the desirable range.

Management impacts on soil health

In a pair of sites on the same farm (STO; Figure 16) soil health scores and the number of soil properties in the desirable range were higher in the less intensively managed site.

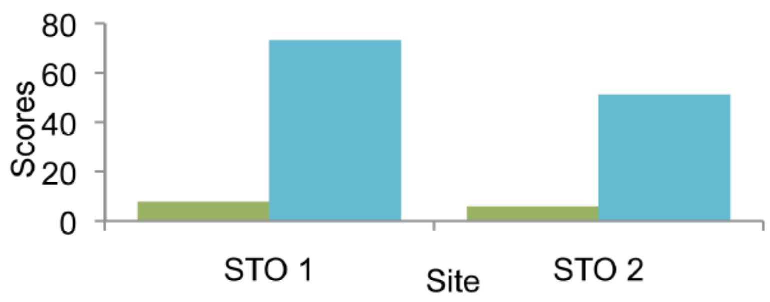

Figure 16. Comparison soil health scores (blue bars) and number of soil properties in desirable range (green bars) at a pair of sites on farm STO. STO1 not grazed for >70 days (less intensive management), where as STO2 had been grazed with moderate-high intensity 4 days prior to sampling (intensive management).

In a pair of sites on the same farm (CLE; Figure 17) soil health scores were higher in a more intensively and salt affected paddock than a less intensively managed paddock. There reverse was seen in the number of soil properties in the desirable range.

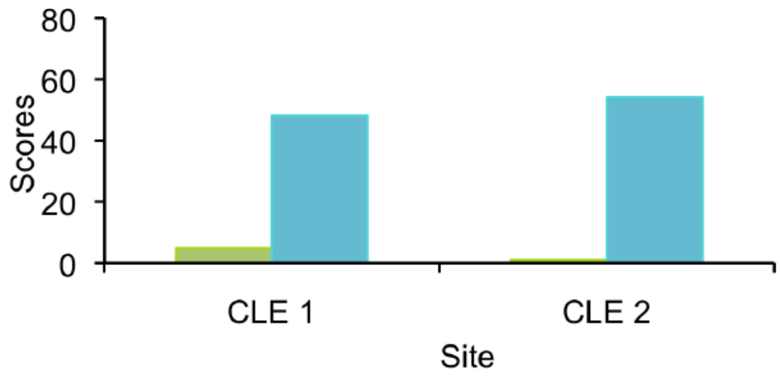

Figure 17. Comparison soil health scores (blue bars) and number of soil properties in desirable range (green bars) at a pair of sites on farm CLE. CLE1 trial paddock plot with no fertilizer additions, cattle grazing at time of sampling (less intensive management), whereas CLE2 salt flats paddock, plot 3 with all fertilizer additions, currently intensely grazed by sheep (intensive management/salt affected).

In a pair of sites on the same farm (AND; Figure 18) soil health scores and the number of soil properties in the desirable range were higher in a less intensively managed site.

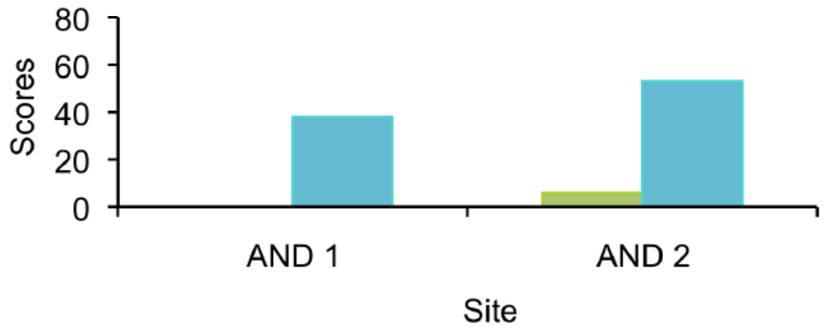

Figure 18. Comparison soil health scores (blue bars) and number of soil properties in desirable range (green bars) at a pair of sites on farm AND. AND1 recently aerated, no cattle for 2 weeks, whereas AND2 paddock (higher plant cover), no aeration, currently grazed by cattle (intensive management).

In a pair of sites on the same farm (MUR; Figure 19) soil health scores and the number of soil properties in the desirable range were higher in a less disturbed site.

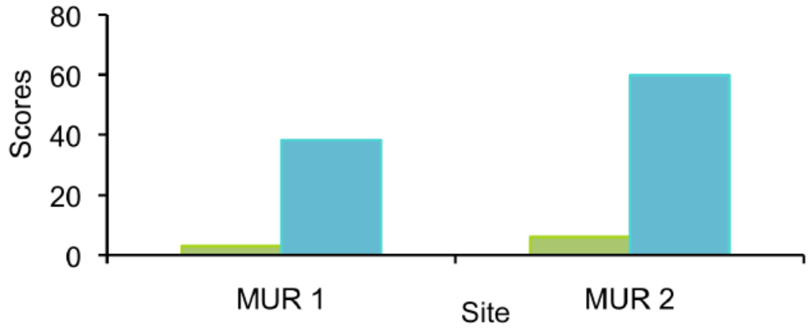

Figure 19. Comparison soil health scores (blue bars) and number of soil properties in desirable range (green bars) at a pair of sites on farm MUR. MUR1 silage taken off, chicken litter added all within two weeks prior to sampling (higher level of disturbance), whereas MUR2 not grazed for some time, hay/silage never made off this paddock (lower level of disturbance).

Key Points:

- In three of four cases the soil health scores, and four of four cases the number of soil properties in the desirable range, were higher in less disturbed or intensively managed (based on farmer records) sites.

Task 2. Methods

Task 2. Critically review the rapid soil health assessment tool developed by Landcare.

The second task involved an assessment of the different parameters included in the soil health tool. Central to this task was an in-field assessment of the implementation of the tool by Landcare staff. This task was undertaken in two ways, as follows:

Assessing the soil health tool and its implementation: a qualitative approach

A descriptive assessment of each of the parameters measured in the soil health tool was undertaken. A brief review of what is measured is given. Factors taken into consideration include scientific validity, easy of implementation, and potentially confounding factors.

Undertaking the soil survey in parallel with the land care assessment of soil health using the rapid assessment tool also allowed for potential technical issues associated with the implementation of the tool to be identified.

Assessing the soil health tool and its implementation: a quantitative approach

To further explore the performance of some of the measures in the rapid soil health assessment tool developed by Landcare, a number of parameters in the tool were compared to other methods of measuring similar properties.

Key Points:

- The rapid soil health assessment tool was critically reviewed using both qualitative and quantitative approaches.

Task 2. Results

Assessing the soil health tool and its implementation: a qualitative approach

The soil health rapid assessment tool developed by Landcare is divided into biological, chemical and physical properties. Within each of these sections a range of soil and/or vegetation properties are assessed, and given scores. The sum of these scores is used to give the overall site soil health score. In the following section of this report we provide a review of each of these elements of the tool. For each of these measures we provide some background information and an assessment of the strengths and limitations of these methods.

A key strength of the soil health rapid assessment tool developed by Landcare is that it recognizes the chemical, physical and biological components of soils, and their important contribution of soil health. In the tool an equal weighting of scores is given to soil chemical and physical properties (maximum possible score of 30 for both) and a greater emphasis placed on soil biological properties (maximum possible score of 40).

Biological components

Earthworm count

Protocol:

- Excavate soil from a 15 cm X 15 cm area to a depth of 30 cm.
- Count worms present in this soil volume.
- Assign score.

Background:

- Earthworms are important members of the soil biota.
- Important role in redistributing organic mater in the soil profile (horizontally and vertical depending on species).
- Organic matter decomposition.
- Creation of macropores, which can improve drainage and provide channels for root growth.

Advantages:

- The inclusion of earthworms in the assessment recognizes the important role earthworms play in improving soil nutrient cycling and structure.
- They are also a readily measured component of the soil biota.
- Benefits of earthworms well understood by stakeholders.

Disadvantages:

- There is a great diversity of earthworms, and thus, a range of impacts they can have on soil processes. The tool does not differentiate between indigenous and introduced/invasive earthworms, which may differ in their function (although this requires a high level of expertise).
- Earthworms are sensitive to disturbance, so sampling should be done quickly.
- Earthworms are not expected to be present in all ecosystems.
- Earthworms are sensitive to soil drying and as such may be present but below 30 cm during drier times of the year.

Recommendations:

- Retain in soil health score.
- Sample immediately to minimize disturbance effects.
- Reconsider inclusion in score card in ecosystems where earthworms are not expected, e.g. sand dunes, some dry-land systems, etc.
- Consider data in context of soil moisture, e.g. season of sampling.

Pasture cover

Protocol:

- Establish 60 m transect across field.
- Record the presence of beneficial pasture species, bare ground or litter at 1 m intervals along the transect.
- Assign score.

Background:

- Recognizes the link between soil health and plant productivity.
- Recognizes benefits of soil health on plants, and importance of plants to soil health.

- The assumption is that the greater the plant cover the greater the soil health.

Advantages:

- Readily assessed in the field.
- Link between soil and plant health well recognized by stakeholders.

Disadvantages:

- Method of measurement may not adequately represent plant cover.
- Potential confusion over method. e.g. does cover refer to cover from above (projected cover), or at the soil surface?
- The score places a very large emphasis on cover values >75%.
- Are weeds better than no cover? The score card focuses on beneficial species, not simply plant cover. In terms of soil health the difference may not be important, but in terms of aboveground biodiversity it may.
- Litter is not well defined. Does this refer to plant litter or any organic matter (e.g. animal feces)?
- Time of measurement will be important, e.g. time since grazing, cultivation and re-sowing, time since cut for silage, season, etc.

Recommendations:

- Retain in soil health score, consider modification.
- Reconsider method of quantification (e.g. quadrates versus point cover, see above) and weighting of scores.
- Carefully define terms.
- Consider timing of assessment, should be same if measuring changes through time.

Root depth

Protocol:

- Excavate in-tact soil sample from 10 cm X 10 cm area to a depth of 30 cm.
- Note presence/absence of roots in different soil zones (depths).
- Assign score.

Background:

- Recognizes the fundamental role of roots in both plant and soil health.

- Roots contribute to soil nutrient cycling, carbon sequestration, aggregation, etc.
- Capitalizes on visible impacts of soil constraints (e.g. compaction) on root development.

Advantages:

- Readily assessed in field.
- Sensitive to changes in soil properties, such as soil compaction.
- Link between soil health and root development, as well as contribution of roots to soil health well understood by stakeholders.

Disadvantages:

- May be susceptible to seasonal variation and time since disturbance (e.g. cultivation).
- Fine roots are important, but difficult to see in the soil.
- While the measure of pasture cover differentiates between weeds and productive species, it is not possible to do this for roots. While not necessarily a “problem”, as weed roots can also improve soil structural stability, etc, it is an internal inconsistency.

Recommendations:

- Retain in soil health score with consideration.
- Consider whether or not a single root at a given depth is sufficient to include that observation in a given depth category.

Depth of Organic Matter.

Protocol:

- Soil profile is assessed for changes in colour as an indication of depth of organic matter.
- Assign score.

Background:

- Organic matter plays an important role in soil nutrient and C cycling, which in turn can have benefits in terms of maintaining and enhancing biological activity in the soil. Organic matter also plays an important role in improving soil structural stability (aggregation).
- Assumes that colour (brown) is a good indication of soil organic matter.

Advantages:

- Readily assessed in the field.

Disadvantages:

- Colour may not accurately indicate levels of organic matter in the soil.
- Large amounts of organic matter may not be visible to the eye, e.g. colloidal material. This may lead to underestimation and/or discrepancies.
- When the mineral soil is already brown, this approach is not suitable.

Recommendations:

- Retain in soil health score with modification.
- If colour is used, consider Munsell colour chart for measuring colour.
- Consider replacing colour as the measure of organic matter with a visual assessment of recognizable organic matter, e.g. decomposing roots, dead soil biota, buried leaf litter, etc. This however, would not capture organic matter in colloidal forms (see above).

Percentage Organic Matter

Protocol:

- Values taken from most recent soil test.
- Assign score.

Background:

- As noted above, organic matter plays an important role in many soil processes.

Advantages:

- This is a quantitative assessment of soil organic mater, rather than a qualitative assessment.

Disadvantages:

- Relies on having a recent soil test.
- The scores are assigned on the basis of soil texture. The textural classes are, however, broad, i.e. Sand, Silt and Clay.

Recommendations:

- Retain in soil health score.
- Consider the impact of time since soil test.

- Need to recognize that organic matter in colloidal form will not be detected.
- There needs to be consistent guidelines for situations where textural class falls between the board classifications, e.g. a Clay-Loam or a Sandy-Clay-Loam, etc.

Soil Chemistry

Soil pH (in CaCl).

Protocol:

- Values taken from most recent soil test.
- Assign score.

Background:

- Soil pH is one of the most fundamental, and informative, soil properties we can measure.
- Provides invaluable information on what chemical reactions are likely to take place in the soil.
- pH regulates the availability of many nutrients.

Advantages:

- A fundamentally important measure of soil chemical properties.
- The importance of pH well recognized by stakeholders.

Disadvantages:

- Relies on a recent soil test.

Recommendations:

- Retain in soil health score.
- Need to consider impact of recent farming activities, such as the application of lime (increased pH) or organic amendments (e.g. chicken litter decreases pH).
- The scores would need to be reconsidered if applied in other ecosystems where the soils are alkaline.
- In-field soil pH tests could be considered.
- Soil sampling needs to be representative.

Cation Exchange Capacity (CEC)

Protocol:

- Values taken from most recent soil test.
- Assign score.

Background:

- Soil CEC is a measure of the capacity for ion exchange between the soil and the soil solution.
- A high CEC indicates increased retention of cations, which decreases the risk of leaching of these ions, but also decreased availability to plants (if values very high).
- Low values indicate risk of leaching of nutrients, which can lead to loss of nutrients and decreased plant availability if nutrients leached below the rooting zone.

Advantages:

- A fundamentally important measure of soil chemical properties.

Disadvantages:

- Relies on a recent soil test.

Recommendations:

- Retain in soil health score.
- Soil texture is an important determinant of optimal CEC values.

N.B. the soil health assessment tool did not include scores when it was provided to the authors of this report. We therefore developed (and used) the following scores. These were based on values given in: Hazelton, P and Murphy, B. (2010.). We also caution that CEC is complex, and there is the risk of oversimplification, for example a soil with a high clay and organic matter content would return a high CEC, but it may not necessarily mean that it is not healthy.

Table 3. Soil health scores for cation exchange capacity used in this project (see text).

Cation Exchange Capacity					
Taken from standard soil test analysis				CEC cmol (+)/kg	
Clay		Clay Loam		Loam	
< 5	2	< 6	2	< 2	2
5.1 – 15	5	6.1 -10	5	2.1- 5	5
15.1 – 25	10	10.1 – 18	10	5.1 – 9	10
25.1 – 35	5	18.1 – 22	5	9.1 – 11	5
> 35.1	2	> 22	2	> 11	2

Leaf colour

Protocol:

- Assess leaf colour and any signs of distortion on plants in paddock.
- Assign score.

Background:

- This measure again recognizes the link between plant condition and soil health.
- Discoloration can be an indication of nutrient deficiency in plants. For example, yellowing of the older leaves can indicate nitrogen deficiency, whereas purpling can indicate phosphorous deficiency.

Advantages:

- Recognizes the link between soil and plant properties.
- Plants are good “integrators” of soil conditions. Thus, if a soil is nutrient deficient, this should be evident in the plants grown in it (with some exceptions).

Disadvantages:

- Discoloration of plant tissue can be caused be a range of factors, e.g. pest and pathogens, pesticide use, etc.
- Different nutrients (and other factors) can cause yellowing of tissue. What is important is the location on the plant (e.g. old versus young

leaves) and where on the leaves the discolouration is observed (e.g. on and/or in between leaf veins).

- It is not clear in the tool how many plants are to be assessed.

Recommendations:

- Retain in soil health score with modification.
- Consider replacing discoloration with presence of nutrient deficiency symptoms.
- A simple key for identification of nutrient deficiencies could be developed for dominant plant species.
- Better define sampling protocol, e.g. assessment could be done in parallel with the pasture assessment.

Macro-life

Protocol:

- Types of visible soil biota are counted in the same soil sample earthworms are counted.
- Assign score.

Background:

- Recognizes the importance of soil biota (in this case visible without the aid of a microscope, hence “macro-biota”) in soil health. Key processes include the breakdown and decomposition of organic matter.
- It is important to note that not all “macro-life” is beneficial, e.g. pest species.

Advantages:

- Recognizes the important role of the soil biota.
- Easily quantified in the field.
- Benefits of “macro-life” well understood by stakeholders.

Disadvantages:

- No differentiation between pest and non-pest species is made. This, however, would require a high level of expertise in pest identification.

Recommendations:

- Retain in soil health score, consider modification.

- Consider compiling list of important pest species for each region and omit these from the soil health score count. Alternatively, it may be more appropriate to adjust scores to take into account the presence of pests.
- Macro-life are sensitive to disturbance, so sampling should be done quickly.
- The abundance of macro-life may differ considerable between types of ecosystems, with no negative impact on soil health. i.e. abundances may be context specific.
- Marco-life are sensitive to soil drying and as such may be present but below 30 cm during drier times of the year.
- Consider data in context of soil moisture, e.g. season of sampling.

Root development

Protocol:

- Excavate in-tact soil sample from 10 cm X 10 cm area to a depth of 30 cm.
- Note presence/absence of fine roots in different soil zones (depths).
- Assign score.

Background:

- As with root depth, recognizes fundamental role of roots in both plant and soil health.
- Roots contribute to soil nutrient cycling, carbon sequestration, aggregation, etc.

Advantages:

- Capitalizes on visible impacts of soil constraints (e.g. compaction) on root development.
- Sensitive to changes in soil properties. This is especially true of fine roots.
- Link between soil health and root development, as well as contribution of roots to soil health, are well understood by stakeholders.
- May be susceptible to seasonal variation and time since disturbance (e.g. cultivation).

- Readily assessed in the field.

Disadvantages:

- Fine roots are not defined in the tool.
- Fine roots can be difficult to see in the soil.
- Categories are based on the presence or absence of roots in a given soil layer. Thus, if there is one fine root present the score is given.
- While the measure of pasture cover differentiates between weeds and productive species, it is not possible to do this for roots. While not necessarily a problem, as weed roots can also improve soil structural stability, etc, it is an internal inconsistency.

Recommendations:

- Retain in soil health score, consider modification.
- Define fine roots, e.g. <2 mm in diameter.
- Consider only assigning a score if the fine root density in a given soil layer is greater than some pre-determined value, e.g. 1 fine root per 1cm^2.
- Consider data in context of soil moisture, e.g. season of sampling.

Physical components

Soil structure.

Protocol:

- Collect soil from soil pit.
- Assess visually and by hand soil structural condition, e.g. presence or absence of soil crumbs and clods.
- Assign score.

Background:

- Provides a measure of soil structure which is linked to the stability and erosion risk for a given soil.

Advantages:

- Readily assessed in the field.
- Known links between soil structure and soil stability.
- The importance of soil structure well understood by stakeholders.

Disadvantages:

- Difference between clods and crumbs not well defined in the tool.

Recommendations:

- Retain in tool with consideration.
- Impact of soil moisture needs to be considered.
- Carefully define clods and crumbs.
- Clods are soil aggregates or lumps that exist as isolated entities for short periods of time and vary greatly in size (Russel and Tamhane 1940).
- Soil crumbs are soil aggregates that are water-stable and their size is dependant upon soil moisture and wetting (Russel and Tamhane 1940).
- Consider data in context of soil moisture, e.g. season of sampling.

Aggregate stability.

Protocol:

- Soil aggregates collected from soil pit.
- Aggregates (of defined size) placed in jar of water.
- Water agitated, and aggregate conditions assessed after defined periods of time.
- Assign score.

Background:

- Soil aggregates are important structural units in the soil.
- The greater the level of aggregation the lower the risk of soil erosion (in many soils).
- Soil aggregate stability is linked to many soil properties, including soil C, root development, organic matter protection, etc.

Advantages:

- Recognizes the importance of a key soil physical property.
- Importance of aggregates well understood by stakeholders.

Disadvantages:

- Method of quantification appears to have low sensitivity.

Recommendations:

- Retain in soil health assessment, with modification.
- Consider alternative methods for measuring soil aggregate stability/dispersion (see Appendix 3).

Penetrometer.

Protocol:

- Soil strength is measured using a hand penetrometer in the 0-15 and 15-45 cm soil layers at 10 randomly selected positions in each site.
- Assign score.

Background:

- Soil strength is a measure of the amount of resistance there is in the soil to penetration.
- Penetrometer readings can provide useful information on soil compaction.

Advantages:

- Recognizes the importance of soil strength and compaction, which can impact upon root development, the movement of soil biota (e.g. earthworms) and water infiltration.

Disadvantages:

- Hand-penetrometers are notoriously variable when used by different operators.
- Soil moisture content can have a large impact on measurement, e.g. a clay soil when wet versus dry will return very different penotrometer readings.
- Spatial variation in penetrometer readings can be large.
- The scores are assigned on the basis of soil texture. The textural classes are, however, broad, i.e. Sand/Loam, Silt and Clay.

Recommendations:

- Retain in soil health assessment with modification.
- Need for careful training of operators to ensure consistency in measurements.
- Outline what should be done when measurements cannot be taken to 45 cm.

- Need to ensure that soil moisture is taken into consideration, e.g. consider sampling at similar moisture contents across sites/samplings.
- There needs to be consistent guidelines for situations where textural class falls between the board classifications, e.g. a Clay-Loam or a Sandy-Clay-Loam, etc.
- Consider increasing samples taken to better account for variation.

General recommendations.

In reviewing the rapid soil health assessment tool developed by Landcare a number of points of interest were identified.

- Overall the rational for inclusion of the different elements of the tool are well justified.
- That many of the measures included will be recognized by stakeholders as relevant, is a strength of this approach.
- In some cases the sensitivity of the methods for assessment will tend to limit the likelihood of detecting change (e.g. root density, variability in penetrometer methods, etc).
- Elements of the tool that rely upon a soil test will be limited by the times since the soil test was taken.
- Soil is extremely heterogeneous. Soil sampling regimes are typically designed with this in mind. Thus assessment at a single point will limit ability to deal with this heterogeneity. However, any increase in sampling effort needs to consider the tradeoffs (e.g. time and labor) associated with making more observations.
- If the tool were to be applied to other ecosystems, the applicability of the scores assigned will need to be taken into consideration.
- The time of year when the tool is used may be important where the desire is to detect change through time. It will also be important to take into consideration impacts of changes in soil moisture.
- Many of the properties measured are sensitive to soil moisture. This needs to be take into consideration, especially when comparisons are made between sites or within sites over time.

- There is a strong need for careful explanation of methods in the tool and training of end-users. This will help to ensure consistency in application, and remove the need for “judgment calls” (e.g. when sites fall between textural classes), which will further improve the performance of the tool.

Key Points:

- The rapid soil health assessment tool developed by Landcare considers a wide range of chemical, biological and physical soil properties.
- While a good number of the measures require no modification, several opportunities for improvement exist, and have been suggested.
- Some measures have a large degree of uncertainty associated with them, and their inclusion in the tool should be carefully considered.
- Careful explanation of terms and training of end-users will improve the performance potential of the tool.
- The tool needs to be used with due consideration of the limitations of the method. This will be true of any on-field assessment, or indeed more detailed assessment of soil health.
- Sampling effort and time of sampling (with respect to soil moisture) are important factors which need to be carefully considered.

Assessing the soil health tool and its implementation: a quantitative approach

As part of the detailed soil assessment, a number of soil properties were measured which elements of the rapid soil health assessment tool act as proxies for. To assess the performance of these proxies these data are now considered.

In-field penetrometer measurements can be used to indicate soil compaction, however, penetrometer measurements are notoriously variable between instrument users, and vary with soil moisture content (see above). Bulk density, which can also be used as a measure of soil compaction, is less open to variation between users and soil moisture content. When the soil bulk density was compared to penetrometer scores in the soil assessment tool (Figure 20) there was little agreement between the two measures.

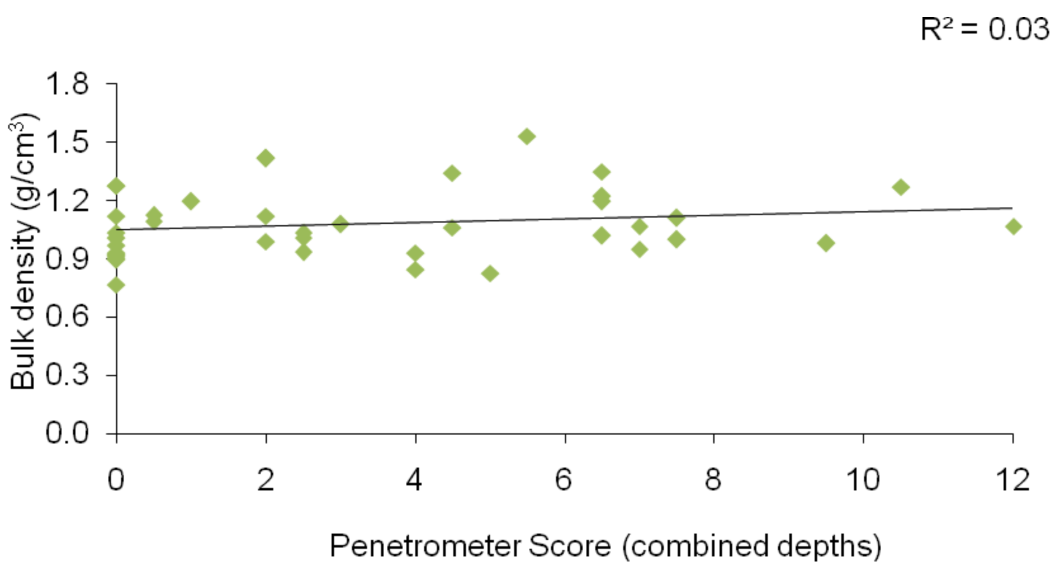

Figure 20. Relationship between combined penetrometer score in the rapid soil health assessment tool and bulk density, by site.

In an effort to assess the performance of the "pasture transect" undertaken as part of the soil health rapid assessment, pasture condition was measured in two ways. The first was a direct measure of pasture biomass on a per unit area basis. The second was a quadrat-based assessment of pasture cover. When compared to the results from the pasture transect, there was little agreement between the biomass (Figure 21) and cover (Figure 22) based estimates of pasture condition.

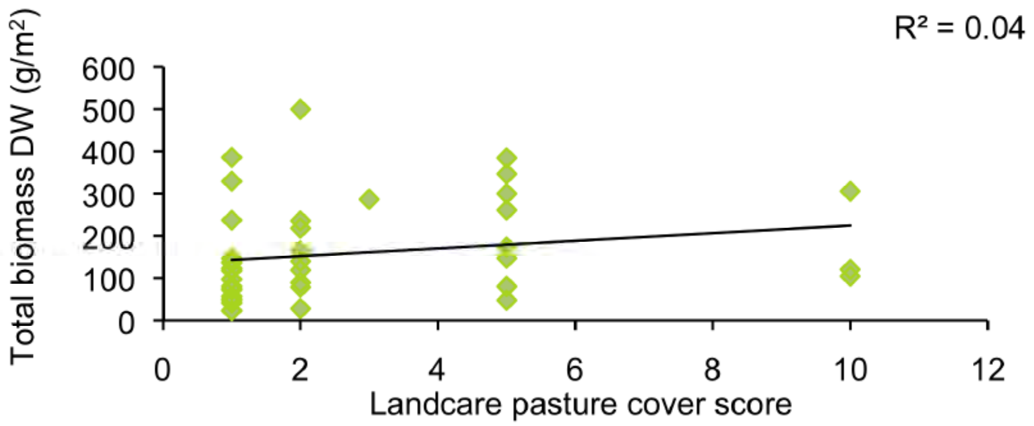

Figure 21. Relationship between pasture transect score in the rapid soil health assessment tool and pasture biomass (on per unit area basis).

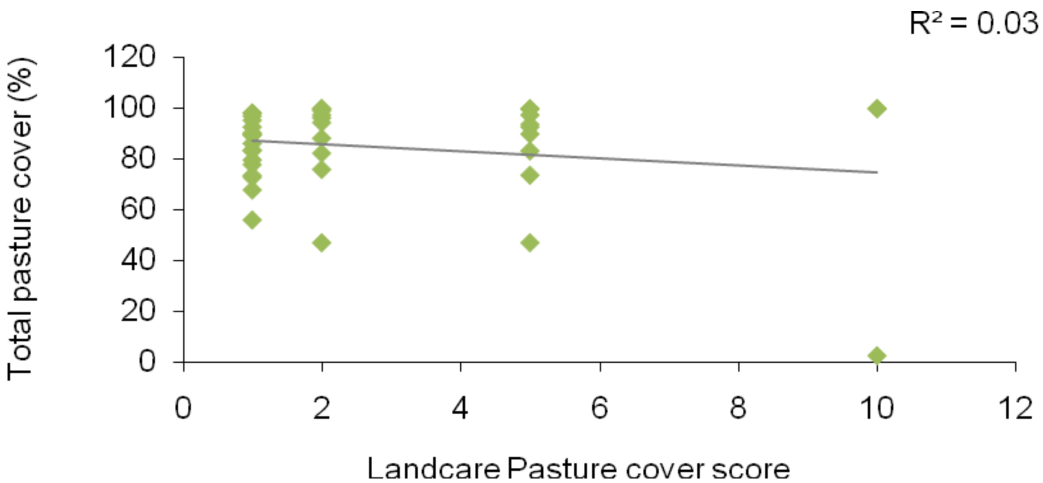

Figure 22. Relationship between pasture transect score in the rapid soil health assessment tool and overall pasture cover (pasture & weeds).

In an effort to assess the performance of the root development and root depth scores in the rapid soil health assessment tool, scores were compared to root biomass measured in the soil. There was little agreement between the visual measures of root development (Figure 23) and rooting depth (Figure 24) with root biomass.

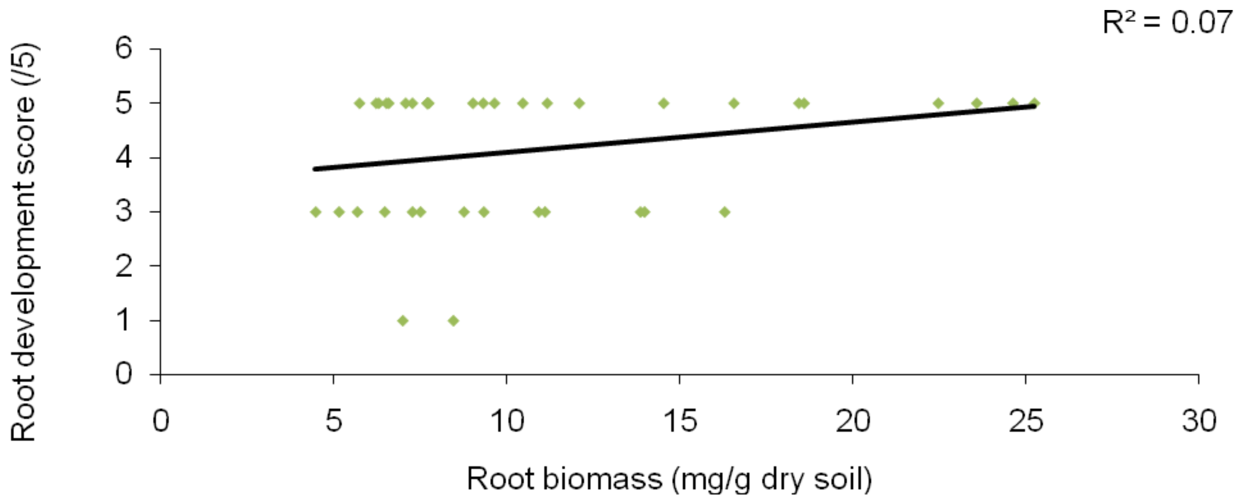

Figure 23. Relationship between the root development score in Landcare's in field soil health assessment and mean root biomass.

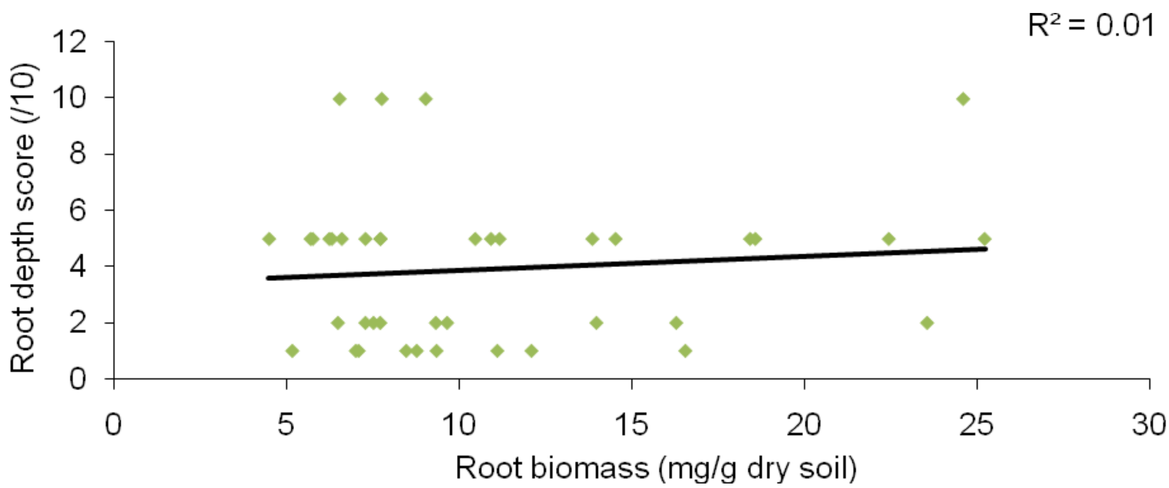

Figure 24. Relationship between root biomass and root depth score in Landcare's rapid soil health assessment tool.

Key Points:

- The level of agreement between some measures in the rapid soil health assessment tool developed by Landcare and more quantitative methods for measurement was low. However, this provides useful information in terms of refining the tool.

Recommendations

Measuring soil health in the field is challenging, but is of high priority. Many different approaches for measuring soil health have been developed. Methods for measuring soil health on a large scale will need to be readily implemented in the field, and likely to detect changes in soil health. To this end, the rapid soil health assessment tool developed by Landcare is readily used, and is similar in its approach to that proposed for use in other contexts. Given the tremendous spatiotemporal variation in soils and soil properties, sampling regimes need to be very carefully designed in any assessment of soil heath. We contend that one of the greatest benefits that can come of measuring soil health is raising awareness of the importance of soil health in the minds of land managers, and the impact that this may have on their future land management decisions. Therefore, given all of these challenges associated with measuring soil health, we consider it commendable that Landcare has taken steps to develop a rapid soil health assessment tool.

In our assessment of the rapid soil health assessment tool developed by Landcare we found some agreement between the number of soil properties to be considered in their desirable range and soil health scores returned by the tool. That the relationship between the two measures of soil health/properties was positive (albeit weakly so) is an indication that the rapid assessment tool is detecting change in the "right direction". Furthermore, it is likely that the tool will be most sensitive where soil health is at the extremes, i.e. very high or low levels of soil health, with less confidence in the mid-range. This however, was not considered in detail here.

When soil health scores and the number of soil properties considered to be in their desirable range were compared, sites with more intensive management were generally found to have lower scores than those less intensively managed. Again, this suggests that the tool is capable of detecting change in the "expected direction". For assessment of change in soil health at the sites sampled in this project, it will be important to assess soil health at times when conditions are similar (e.g. soil moisture, time of year, time since management intervention, etc, see below also).

In undertaking this review a number of specific issues have been identified, leading to the following recommendations (in no particular order).

Overview of tool elements: Some aspects of the tool could be modified to improve performance. These are detailed in the report and summarised in Table 4.

Table 4. Overview of performance of rapid soil health assessment tool developed by Landcare. N.B. This Table should only be considered in parallel with recommendations given in the text of this report.

Components	**Parameters**				
Biological	Earthworm count	Pasture cover	Root depth	Depth of OM	% OM
	[Green]	[Red]	[Yellow]	[Red]	[Green]
Chemical	pH in CaCl	CEC	Leaf color	Macro life	Root development
	[Green]	[Green]	[Red]	[Yellow]	[Red]
Physical	Soil structure	Aggregate stability	Penetrometer (0-15cm)	Penetrometer (15-45cm)	
	[Yellow]	[Red]	[Red]	[Red]	

Green = No change accept as is/with current modifications.
Yellow = Consider clarification
Red= Consider modifications

The need to assess performance in other ecosystems/contexts: The soil health rapid assessment tool was assessed in the context of grazed pasture based systems within the Bass Coast, Westernport and South Gippsland Landcare group regions, in Victoria. This is also the context in which the tool (and scores therein) were developed. Any future application of the tool in other regions and management contexts will require careful consideration. That is, soil health scores will be context specific, for example, scores for a healthy forest soil may be very different from those of a healthy dune soil. Other such differences in context, e.g. land use type, agricultural management and location should also be considered in the context of measuring soil health. This will more than likely require some context specific modification of the tool.

The value of repeated measures cannot be underestimated: It may be that the tool is most useful in measuring changes in scores rather than absolute values (assuming sampling is done in a repeatable way). To this end, the time when the tool is used also needs to be carefully considered. Measuring change through time will require soil health to be assessed under similar environmental conditions (unless the aim is to assess changes in soil health score with season and/or environmental conditions, etc). Important factors may include season and time since management intervention (e.g. tillage, grazing, fertiliser addition, etc), amoung others. For example measuring some properties when the soil is wet versus dry will yield large differences in some soil properties in the rapid soil health assessment tool (see report for examples).

The relative weighting of scores needs to be considered: A soil may have all properties with high scores, but one key property may be very low. Thus, a soil may be given a high soil health score, but there may be a serious underlying problem in one area, e.g. a very low soil pH. This could be addressed by highlighting very low or high values of particular soil properties in soil health score cards.

Terms need to be carefully defined, and protocols standardized: The rapid soil health assessment tool covers many key elements of soil health. There is however, some room for improvement in terms of defining terms and ensuring consistency in application in the field (see report and Table 4 above).

Results need to be interpreted in light of any limitations of the tool: The tool needs to be used with due consideration of the limitations of the method. For example, results are based on a single soil pit. While an additional soil pit would provide more information, this would increase time spent assessing each site. That is, there are tradeoffs that need to be considered. This will be true of any in-field assessment, or indeed more detailed assessment of soil health and soil properties.

The importance of raising awareness: Again, we reiterate the fact that simply measuring soil health has many benefits, especially in terms of raising awareness of the impacts of land management decisions. We therefore recommend that the tool be used as part of education programs implemented by Landcare.

Some measures need to be carefully reconsidered: Some measures of soil and vegetation properties did not perform well when compared to more detailed methods of assessment. These include (but are not limited to) the pasture transect, penetrometer readings, and soil structural stability. As outlined in the report, we recommend that pasture condition be determined using cover estimates (see Figure 25), that penetrometer measurement be better standardised and more reading be taken, and that soil structural stability be measured in aggregate dispersion tests (see Appendix 3).

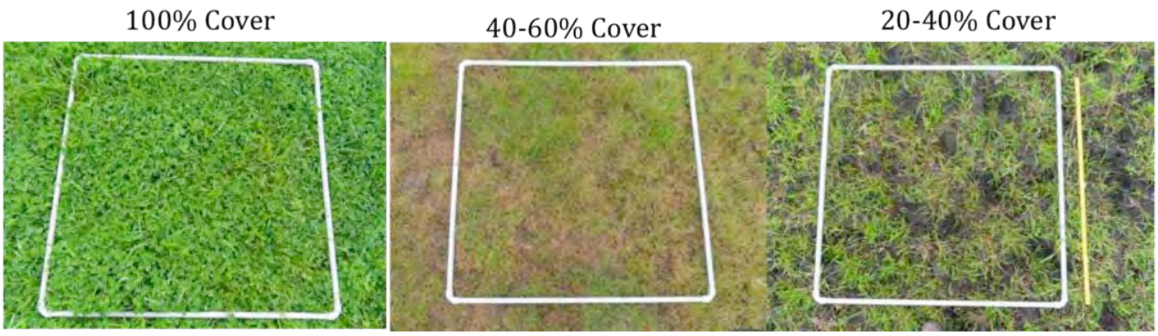

Figure 25. Vegetative cover estimates using 1 m X 1 m quadrats.

The need to tailor tool to different ecosystems, e.g. textural classes/soil types and scores: Greater specificity in soil textural classes will be useful in the use of the tool in the field. For example, how should a Clay-Loam be classified in terms of the broad categories of Sand, Silt and Clay? Irrespective of how this issue is dealt with, this needs to be consistent across all users of the tool. As noted above, if the tool is to be used in different regions different scoring systems may need to be developed to reflect local soil types.

Concluding remarks

There are considerable benefits to be had by measuring soil health in the field. The rapid soil health assessment tool developed by Landcare represents an important step in achieving this outcome. In the context in which it was assessed here, the tool gave a generally similar indication of soil health when compared with other measures of soil properties. It is, however, likely that the tool will be most sensitive at the extremes of soil health. It is likely that the tool will be of use where it is used to assess change through time (e.g. after a change in soil management), or when comparing soils under different types of management/landuse (with all other variable held the same, e.g. soil type, soil moisture, season, etc). Some aspects of the tool could be refined to improve its performance. We caution that the results of the work presented here should be consider in the context in which the work was undertaken, that is, direct extrapolation of these results to different parts of the landscape or different landuse types and soil types may be misleading. Therefore, the potential to use the tool in other contexts will require additional work, including, but not necessarily limited to, assessment of the tools performance in different settings, and setting scores in the tool that are context specific/appropriate for different landscape and landuse contexts and soil types.

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