Investigation of soil factors associated with the productivity and sustainability of vegetable production in Australia

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VG99057: A survey approach to investigate the soil factors associated with the productivity and sustainability of vegetable production in Australia

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Media Summary

Soil health is a complex web of many interrelated soil properties that are influenced by climate, soil type and management practices. This feasibility study was conducted to examine and compile as much data as possible on soil properties, field information, and suitable indicators that relate to soil health, and to gain a better understanding of their impact on crop yields. Soils were collected from many different cropped and reference sites in major production areas over two crop growing seasons in Queensland, New South Wales, Victoria and Tasmania.

In this project, considerable attention was given to defining the concepts of soil health and their potential indicators in layman's terms. In general, this study highlighted the great potential of quantitative analytical measurements for determining soil factors that impact on crop productivity and for defining the status of a particular soil in relation to a healthy soil. Some of the key findings of this study are briefly outlined below.

Impact of soil factors on crop productivity

- This study indicates that the types of soil factors and management practices that have a major influence on crop productivity are crop specific and can, therefore, only be used in relation to the crops that were studied. Carrot production is sensitive to a decline in soil health. Soil degradation, however, has less impact on capsicum production, because many of the adverse impacts on root growth can be compensated for by intensive farm management practices that include soil fumigation, plastic mulching, multiple fertiliser applications and increased soil tillage. Therefore, when determining the long-term sustainability of crop production, we need to look beyond crop yield alone. High crop yields that can only be obtained through high farm inputs are not sustainable when weighed against the high costs of labour, agrochemicals, and water, as well as the on-site and off-site environmental effects.

Indicators of soil health

- The term "soil health" has a very broad definition. Essentially, it defines a soil's resilience in sustainable productivity, maintaining environmental quality, and promoting plant, animal and human health. Realistic benchmark values for a healthy soil in each region could be obtained from non-cropped reference sites.

- Potential soil health indicators can be broadly divided into two categories, in accordance with their functions. In layman's terms, one category is akin to a building (soil structure, aggregate stability, penetration resistance, soil structure score) and the other is akin to building materials that will influence the quality of the building (organic matter, air pores, total microbial activities, fungi, bacteria, nematodes). This comparison highlights the importance of the latter in the overall health of a soil. Soil microflora (bacteria and fungi) and microfauna (nematodes) are particularly sensitive to organic matter, soil disturbances and management practices. Therefore, these dynamic biological indicators could serve as an early warning system for practices that can affect soil resilience.

- Soil carbon was identified as the basic and most important building component for a healthy soil, irrespective of soil type, region, or climatic conditions. Some cropped sites in Tasmania and Queensland showed similar or higher soil carbon values than their comparable reference sites. This indicates that with good farm management practices, even with intensive land use for vegetable production, soil integrity and soil health can be sustainable.

Technical Summary

Soil health is a complex web of many interrelated soil properties that are influenced by climate, soil type and management practices. This feasibility study was conducted to examine and compile as much data as possible on soil properties, field information, and suitable indicators that relate to soil health, and to gain a better understanding of their impact on crop yields. Soils were collected from many different cropped and reference sites in major production areas over two crop growing seasons in Queensland, New South Wales, Victoria and Tasmania.

In this project, considerable attention was given to defining the concepts of soil health and their potential indicators in layman's terms. In general, some of the key findings of this study are briefly outlined below.

Impact of soil factors on crop productivity

- Capsicum and carrot crops were used as benchmark crops for this feasibility study. The study indicated that the types of soil factors and management practices that have major influences on crop productivity are crop specific and can only be used as indications for those crops that were studied.

- Carrot production is directly affected by a decline in soil health, with impacts on both carrot root growth (carrot shape) and carrot susceptibility to soilborne diseases. Soil degradation, however, has less impact on capsicum production, because many of the adverse effects on root growth can be compensated for by intensive farm management practices that include soil fumigation, plastic mulching, multiple fertiliser applications and increased soil tillage.

- As a result, this study also demonstrated that crop yields were not always influenced by soil properties that are closely related to soil health. Many resulting adverse effects of soil degradation, such as carbon depletion, poor water retention, decline in soil structural properties, and decline in beneficial soil organisms, can be compensated for.

- The use of crop yield as a measure of soil decline can also be misleading, as yields can also be increased through the introduction of high yielding new varieties, salt tolerant varieties, an improved range of fertilisers, better disease and pest control, and improved technology in farm management. Therefore, when determining the long-term sustainability of crop production, we sometimes need to look beyond crop yield alone. High crop yield that can only be obtained through high farm inputs is not sustainable when weighed against the high costs in labour, agrochemicals, and water, and the on-site and off-site environmental effects.

- A major challenge to vegetable growers and researchers will be to develop management practices that will reduce reliance on chemical inputs and ensure the effective use of water, while also preserving environmentally friendly land use for plant, animal and human health. It is conceivable that in evaluating a cost benefit ratio, growers may have to consider lower yields for a lower cost farm input production system. These are the issues that can only be addressed though long-term evaluations to identify and develop alternative options to the current intensive and high input management systems.

Indicators of soil health

- The term "soil health" has a very broad definition. Essentially, it defines a soil's resilience in sustainable productivity, maintaining environmental quality, and promoting plant, animal and human health. Realistic benchmark values for a healthy soil in each region could be obtained from non-cropped reference sites.

- Potential soil health indicators can be broadly divided into two categories, in accordance with their functions. In layman's terms, one category is akin to a building (soil structure, aggregate stability, penetration resistance, soil structure score) and the other is akin to building materials that will influence the quality of the building (organic matter, air pores, total microbial activities, fungi, bacteria, nematodes). This comparison highlights the importance of the latter in the overall health of a soil.

- Soil microflora (bacteria and fungi) and microfauna (nematodes) are particularly sensitive to organic matter quality and quantity, soil disturbance and management practices. Changes in other non-biological soil properties, such as total carbon, total nitrogen, soil aggregation, compaction, water holding capacity, soil pH and electrical conductivity will also affect these biological indicators. Therefore, these dynamic biological indicators could serve as an early warning system for practices that can affect soil resilience, and may provide a better understanding of changes in organic matter, and conditions in the soil ecosystem.

- In general, higher levels of biological activities were recorded in the reference sites than in cropped sites, regardless of the different methodologies used. Hence, the different methods for determining soil microbial population and activities result in comparable conclusions and are indicative of changes in the soil environment. Useful methods identified in this study include nematode count, fluorescein diacetate hydrolysis, microbial biomass carbon, and PL-FAME analysis.

- Unfortunately, apart from the general impact of disturbed soils (cropped sites) versus undisturbed soils (non-cropped pasture reference sites), the impact on these microbiological indicators by various crop management practices could not be properly assessed in this survey study. Long-term field trials of at least five years, involving replicated plots with different management practices, are required for comparative studies.

- Soil carbon was identified as the basic and most important building component for a healthy soil, irrespective of soil type, region, or climatic conditions. Soil carbon impacts on many biological, chemical or physical soil properties. Some cropped sites in Tasmania and Queensland showed similar or higher soil carbon values compared to reference sites. This indicates that with good farm management practices, even with intensive land use for vegetable production, soil integrity and soil health can be sustainable.

- Unfortunately, with so many variables between the different sites in this survey study, it was not possible to identify what constituted good farm practices and sustainable land use.

Recommendations

This feasibility study established the potential of determining soil factors that impact on crop productivity and the use of potential soil health indicators. The full benefit of this study to the vegetable industry can only be realised with some follow-on work as listed below.

- At the very least, the production of a booklet on soil health for growers and industry use is recommended. Many of the concepts of soil health and explanations on how the various soil components influence soil structural integrity, as presented in this report, should be extended to the wider community in order to generate improved understanding of the relevance of the soil's biological, chemical and structural properties.

- Conduct a review of available data on soils to produce a practical checklist or benchmark values and remedial steps that can be used on poor soils. This would provide an invaluable source of reference for the vegetable industry.

- Long-term studies, of at least 5 years, are essential to gauge the impact of different crop management practices on soil health and soil resilience. The identification of good farm management practices that conserve soil carbon, maintain soil health and crop productivity, even under intensive land use, will benefit many growers.

- Another major challenge will be to develop management practices that will reduce reliance on chemical inputs and increase the effective use of water, while also preserving environmentally friendly land use for plant, animal and human health. This may require the development of an economic benefit method that accounts for the overall farm inputs, effects on soil health and the cost to the environment.

1. Introduction

1.1 Background

Soil is a basic natural resource that provides a vital link to plant, animal and human health. It is the medium for plant growth, recycling and detoxification of organic materials and chemicals, and for recycling many nutrients and gases. In recent times, soil degradation and soil health have become major concerns because of their adverse impacts on local, regional and global scales (Bezdicek et al. 1996).

Many of the conventional vegetable production methods (e.g. tillage, application of inorganic fertilisers, use of plastic mulch, soil fumigation, and compaction by heavy machinery) can lead to soil degradation and the demise of beneficial organisms that live in the soil. Anecdotal evidence suggests that declining soil health has become a major issue for Australia's vegetable industries. However, there is a lack of understanding of which soil factors are involved and how these impact on crop productivity.

Similarly, there is a lack of comparative data that can be used as a benchmark to determine the extent of changes in soil health due to long-term crop production, management practices, and climatic conditions. When available, information on the status of soil health and the level of soil degradation, particularly in vegetable crop soils in Australia, is often vague, subjective or incomplete. This is because the scopes of most studies relating to the above issues are often limited, where different aspects of soil quality are examined separately, either in disease management, cultivation, agronomy, or chemical and structural properties. Yet, all of these factors are usually interconnected. The concept of healthy soil as an active biological reservoir of beneficial soil organisms is also often overlooked as a contributor to good plant health, maintenance of good soil structure and disease suppression.

The wide range of methods developed for measuring different aspects of soil health also needs to be put into perspective in terms of their suitability, usefulness for different soil types and how some of the related measurements compare against one another.

Soil health is a complex web of many interrelated soil properties that are influenced by climate, soil type and management practices. It is this complex relationship that makes a comprehensive quantitative measurement of soil health a challenging task for researchers, and requires substantial commitment of funds. As an initial step, this preliminary survey project was proposed as a way forward by Horticulture Australia Limited and key researchers to determine the feasibility of such an undertaking.

5. General Discussion

5.1 Crop productivity and soil factors

Findings in this study indicate that soil factors and management practices that have major influences on crop productivity are crop specific. This is not surprising, as different types of crops have different requirements.

Capsicum production

A capsicum crop is established using transplants, has relatively weak and shallow root systems, and hence requires substantial and multiple nutrient and water input during crop growth. The high dependency on irrigation, fertiliser and pesticide applications can help negate the consequences of poor root development. The adverse effects of soil degradation, such as carbon depletion, poor water retention, decline in soil structural properties, and decline in beneficial soil organisms, can be compensated for, but at an increasing cost to the production system.

In this study, the two main factors identified as having major influences on capsicum yield were increased nitrogen application and increasing numbers of passes with a tillage implement. In contrast, management practices and soil properties that contributed to a healthy soil had no significant influence on the yield of capsicum. It should also be noted that the high number of soil types (Black Vertosol, Alluvial, Black Dermosol, Brown Dermosol, Yellow Dermosol, Grey Sodosol, Grey Chromosol, Redoxic Hydrosol, Red Kandosol and Podosol) included in the survey could have resulted in too much variability for statistical significance in the results.

The analysis of crop productivity also showed that in determining the long-term sustainability of crop production, we may need to look beyond crop yield alone and at longer time periods. So, even though high yields could be obtained from the capsicum crops with high inputs, the economic sustainability of the production system must be weighed against the high costs of labour, chemicals and water, and the long-term environmental impact.

Soil fumigation, either with methyl bromide or metham sodium (**Photograph 7**), is regularly used to optimise soil conditions for capsicum production. The use of methyl bromide is being phased out due to its adverse effects on the environment, while reduced efficacy of metham sodium, due to enhanced degradation, is becoming common. The cost of water and rights to water are becoming major issues in agriculture, as it is competing with households, river systems and the general environment for a scarce resource. High reliance on fertilisers results in off-site impacts such as increased soil salinity, and leaching of nutrients to underground waterways.

Photograph 7: A truck loaded with metham sodium, a soil fumigant.

A major challenge for capsicum growers and researchers will be to develop management practices that will reduce reliance on chemical inputs and more effectively use water, while also preserving a healthy landscape for use by plants, animals and humans. It is conceivable that in evaluating a cost benefit ratio, growers may have to consider lower yields for a lower cost farm input production system. These issues can only be addressed through long-term studies to identify and develop alternative options to the current intensive and high input management systems.

Carrot production

A carrot crop is established with direct seeding and has a deep tap root system (**Photograph 8**). Unlike capsicums, fertiliser is often only applied just before or at sowing. As a root crop, it is highly dependent on root growth and appearance, and therefore, it is greatly influenced by soil properties and soil management practices, especially in heavy clay and clay loam soils.

Photograph 8: Carrots, a root crop

The extent to which soil conditions influence carrot production also depends on carrot varieties and the market they are produced for. Carrots produced for the fresh market face the greatest hurdle, as they must meet market criteria for perfection in size and shape, be blemish free, and suitable for long-term cold storage. In contrast, there are much higher tolerance and threshold limits for these criteria on carrots produced for processing into frozen vegetables or juice.

The levels of farm input in carrot production depend on the state, regional areas, and soil type. For example, fresh market carrots in Tasmania are generally produced in organically rich ferrosol soil (clay loam), have one early fertiliser application, and irrigation applied once or twice a week in summer. This is in contrast with fresh market carrots produced in Western Australia, usually in sand with little or no organic matter, requiring regular weekly fertiliser applications and daily irrigation in summer. This shows that in practice, carrots can be produced in sand but at a much higher expense in terms of farm resources. Soil fumigation, which is rarely used in Tasmania, is frequently used in WA prior to sowing. In NSW and Victoria, the carrot crops surveyed were also produced with relatively low farm inputs, and without soil fumigation.

In Tasmania, where all crops surveyed were produced in the same soil type (Red Ferrosol), the main causes of decline in carrot packout or quality of fresh market carrots were diseased and misshapen carrots. However, carrot packout improved as total soil carbon increased. Soil carbon is, therefore, an important measure of soil health, and it has many influences on soil physical, chemical and biological conditions.

The main factors that directly influenced levels of disease in carrots were topsoil compaction and soil erosion. Thus, the amount of disease increased with an increase in topsoil penetration resistance and with an increase in topsoil erosion. The main factors that influenced misshapen carrots were soil preparation prior to sowing, types of soil aggregates, and crop management practices. This shows that the tap roots of carrot seedlings are susceptible to adverse soil structural conditions, and this results both directly and indirectly in misshapen or diseased carrots. Similarly, in NSW, carrots produced in the heavier Vertosol soil in the Beneramba region are also prone to be more misshapen than those produced in the lighter Red Kandosol of the Cookathama region.

Soil structural properties are the resulting composite of many factors such as climatic conditions, soil type, organic carbon, soil organisms, soil management and machinery. A greater understanding of how management practices affect these factors can help us improve or maintain soil resilience and productivity.

This study shows that the key soil health factors that were identified in carrot production are also soil specific. In other vastly different soil types, such as sandy soils, further studies are required to determine the key soil factors involved. Furthermore, in a survey type study, tests must be conducted on at least 30 to 40 sites from a given soil type to enable meaningful comparisons. The low number of sites examined in NSW and Victoria due to funding constraints made it almost impossible to extract substantial findings on carrot production in those states.

5.2 Organic matter & soil health

The term soil quality or soil health has a very broad definition. Essentially, it defines a soil's capacity to sustain biological productivity, to maintain environmental quality, and to promote plant, animal and human health. Apart from use for agriculture, soil also functions as a living filter to protect our environment by breaking down and recycling organic wastes, chemicals, and pollutants in the environment (Hellkamp et al. 1994). For example, it recycles many nutrients for plant growth, helping to recycle and detoxify organic materials, pesticides, and global gases. Therefore, the definition of soil health involves more than the capacity of soil to produce crops. Indicators for a healthy soil should include evaluations of a soil's capacity to perform environmental and health functions, as well as productivity.

In this feasibility study, non-cropped soils that are under long-term pasture or grass were used as ideal references for comparing with vegetable cropped soils to determine changes in the soil characteristics. This assumes that the reference soils contain the ideal or desirable characteristics. We must also note, however, that there may be exceptions, where sound agricultural practices can enhance soil health through improvement of organic matter, nutrient status, drainage, and physical and biological characteristics.

<u>Organic matter</u>

There is a general consensus among soil scientists that soil organic matter is a key aspect of soil health. In the broadest definition, soil organic matter consists of living organisms, slightly altered plant and animal organic residues, and well decomposed organic residues (Magdoff 1992).

Soil organic matter is a reservoir of plant nutrients in soils, and is important in maintaining soil tilth, aiding infiltration of air and water, promoting water retention, reducing erosion, and controlling the efficacy and fate of applied pesticides (Sikora & Stott 1996). It influences soil productivity, by serving as a storehouse for plant nutrients that are released slowly, in supporting a diverse soil organism population, thereby helping suppress plant diseases and pests (Sikora & Stott 1996). Its dark pigmentation also assists in the absorption of heat, thus acting as a heat reservoir. Soil organic matter also impacts on the partitioning of precipitation that affects soil in productivity, soil erosion by water, and water conservation (Stevenson 1994). Organic matter increases the water holding capacity of soil, thereby decreasing the potential for saturated soil conditions and runoff events.

<u>Soil health</u>

Although organic matter influences so many soil factors, a measurement of organic matter itself will not provide sufficient information for how it impacts on soil health. Useful information can be obtained, however, by measuring other soil indicators that are influenced by the composition of organic matter and are highly sensitive to changes in management practices. Other indicators, based on visual or analytical assessments, may help provide a better understanding of the status of soil health in vegetable production. Potentially useful indicators examined in this study will be discussed in **Section 5.3**.

5.3 Status of soil health & potential indicators

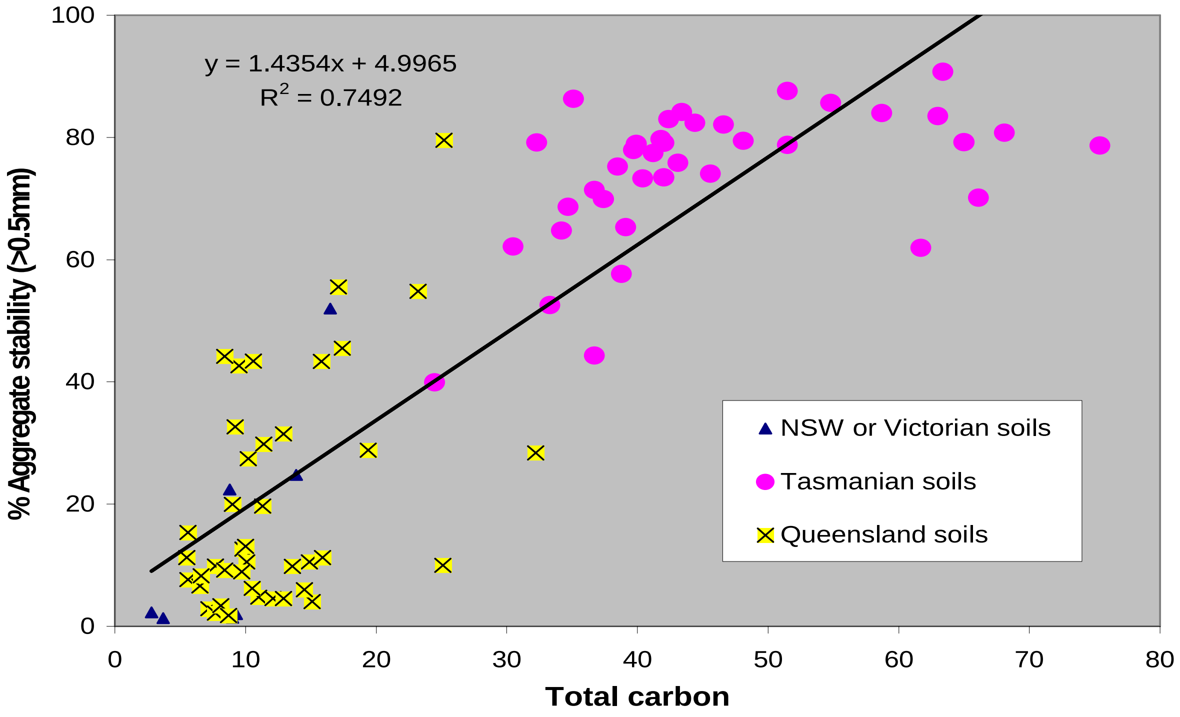
Aggregate stability & soil carbon

The status of aggregate stability and soil carbon in the surveyed soils in Queensland, Tasmania, NSW and Victoria is shown in **Figure 5.1**.

Aggregate stability refers to the resistance of soil aggregates to breakdown by water and mechanical manipulation. Improved aggregation increases porosity, especially for macrospores, which favors a high infiltration rate, good tilth and adequate aeration for plant growth. Aggregate instability or breakdown by rainfall results in plugging of pores by fine aggregates or particles, restricts infiltration rate, and may cause surface sealing (soil crusting) and anaerobic conditions. Maintenance of crop residues on the soil surface, as is the case with conservation tillage systems, protects the soil surface against raindrop impact, thus reducing aggregate breakdown and surface sealing. Microorganisms also decompose the residue and produce compounds that stabilise aggregates.

The aggregate stability of soils from Tasmania was relatively high compared to those from Queensland, NSW and Victoria (including reference soils). These differences were related to the lower soil carbon levels, different soil types, and warmer soil temperatures in the other states. However, the wide range of values for aggregate stability and total carbon between the individual sites in Tasmania and Queensland indicates that farm management practices are also likely to have a significant impact.

Figure 5.1: The relationship between aggregate stability and total carbon of soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.

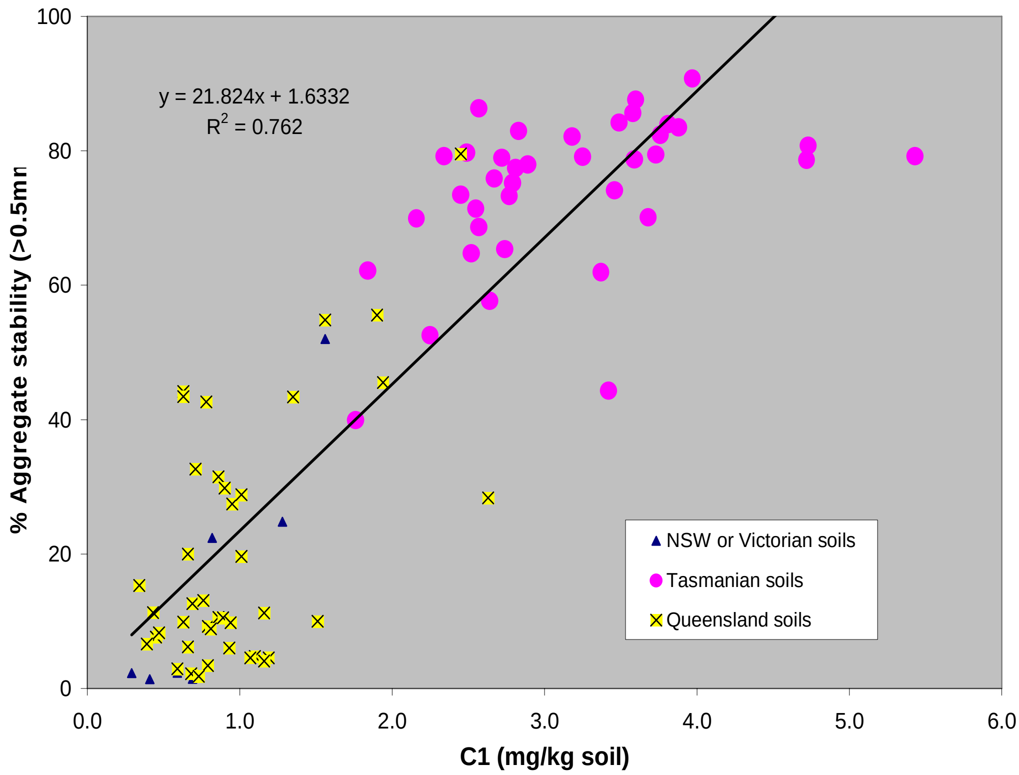


Some cropped sites in Tasmania showed similar or slightly higher values in both measurements compared to reference sites. This indicates that with good farm management practices, even with intensive land use for vegetable production, soil integrity and soil health can be sustainable. Unfortunately, in this survey type study, with so many variables between the different sites, it is difficult to pinpoint what constitutes good farm practice and sustainable land use. Soil carbon is believed to be vital for aggregate stability and many other soil properties that contribute to the health of a soil.

Like total carbon, C1, which is readily oxidisable and hence the most accessible type of carbon, is also closely correlated to aggregate stability (**Figure 5.2**). This relationship highlights the importance of organic matter and microbial activities in affecting soil structural properties. The similarities in the relationships between aggregate stability and total carbon and C1, indicates that total carbon, which is routinely measured in commercial soil analysis is a useful indicator for soil health.

Much of the organic carbon in soil is non-living and relatively stable with a very slow rate of turnover (e.g. 90 to 95% of the total carbon may be stable carbon). Therefore, decades may be required to detect any measurable changes of total carbon or organic matter in soil. In contrast, microbial biomass in soil is a living component of soil organic matter, with a rapid turnover of less than one year (Rice et al*.* 1996), and in other studies, C1 has been shown to be correlated with both microbial biomass (Moody et al*.* 1999) and with the key soil chemical properties of cation exchange capacity and pH buffer capacity (Moody et al*.* 1997). Furthermore, as shown in **Figure 5.2**, C1 is correlated with aggregate stability (a key soil physical property), and is sensitive to management practices. C1 may, therefore, be a useful soil health indicator.

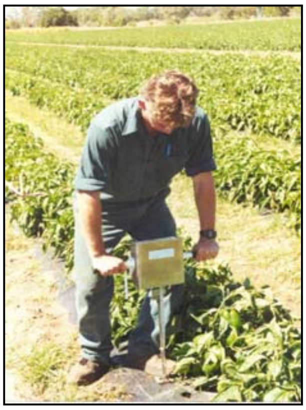
Figure 5.2: The relationship between aggregate stability and labile carbon C1 of soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.



<u>Soil structure score & penetration resistance</u>
Soil structure score, a visual score method, could also offer a quick, easy and low cost method of assessing soil aggregates and soil structural conditions on farms. A soil structure scorecard has been developed for use on Tasmanian Red Ferrosol - clay loam textured topsoils (**Appendix 4**). Similar scorecards can be developed for other soil types.

Penetration resistance is the capacity of the soil in its confined state to resist penetration by a rigid metal probe, and hence is useful for evaluating root growth limitations as well as soil compaction (**Photograph 9**). As soil penetration resistance is dependent on its moisture content, readings taken at field capacity are recommended for comparisons.

However, penetrometer measurements have their limitations, as unlike a rigid penetrometer, a root can diverge from its direct line of advance when a resistant aggregate is in its way. In untilled soil, roots often by-pass resistant barriers using channels left by earthworms and decayed roots. These channels are destroyed in tilled soils.



Photograph 9: A mechanical soil penetrometer

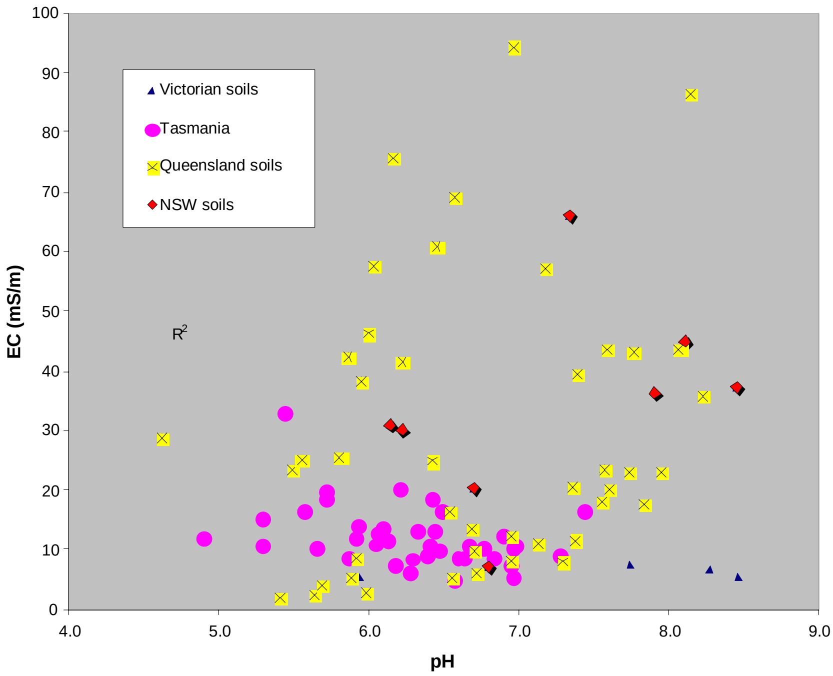
Soil EC and pH

The parameters of electrical conductivity (EC) and pH, often measured in commercial soil analysis, can provide valuable information for assessing soil chemical conditions for plant growth: namely salinity, cation exchange, and availability of nutrient elements.

EC is a measurement of how well a solution conducts electricity. It is used for indicating soil salinity. Soil acidity or alkalinity is indicated by soil pH, which is a measure of hydrogen ion (H^+) activity in the soil solution. The main pH effects of soils are on the availability and toxicity of elements such as aluminium, manganese, iron, zinc, boron, and molybdenum. Soil pH can be an important determinant of different microbial groups in relation to microbe-mediated processes in nutrient cycling (e.g. nitrification and denitrification), soilborne diseases, and breakdown of chemical residues.

When measured together, both EC and pH provide an indication of the chemical status of a soil, and the effects of management practices on soil health. The EC and pH values of surface soil (0-15 cm deep) and subsoil (45-60 cm deep) are shown in **Figures 5.3 & 5.4**.

Figure 5.3: The EC and pH of surface soils (0 to 15 cm) from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.

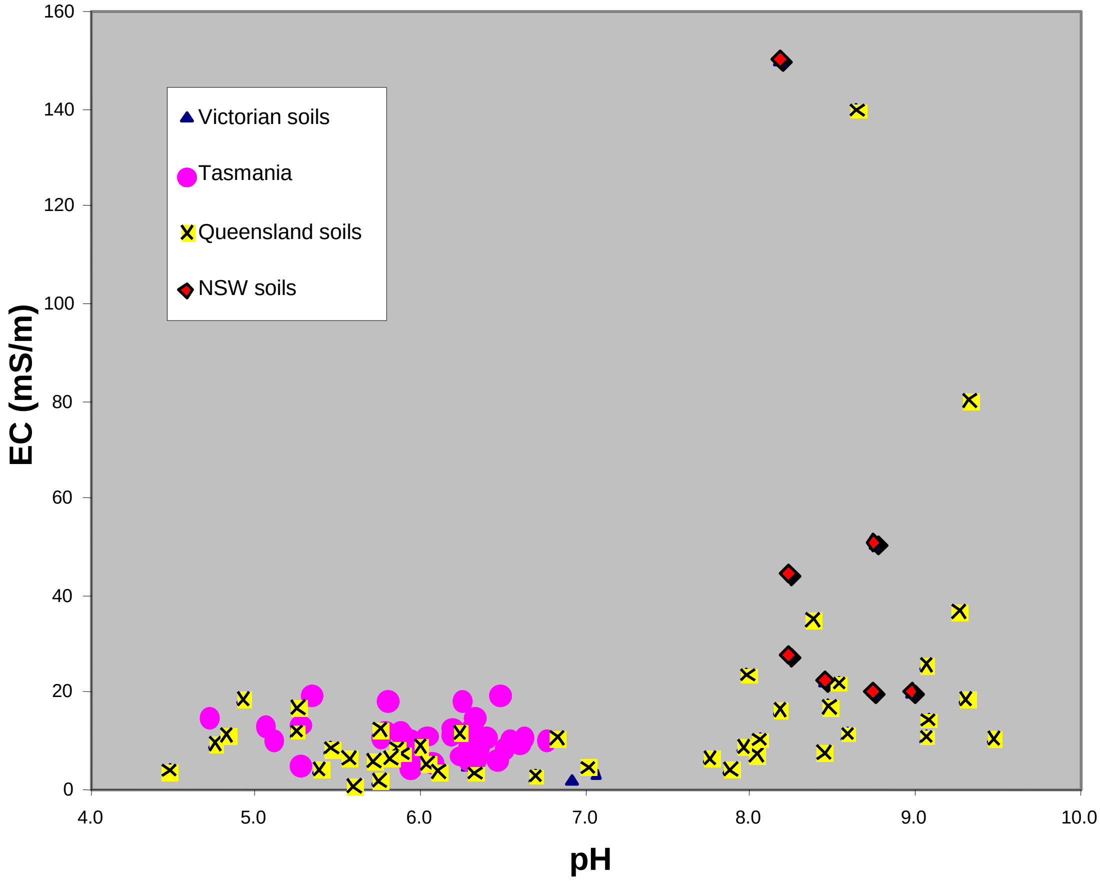


In general, most of the pH (1:5 water) values are within acceptable limits (pH range of 5.5 to 7.5) for plant growth and microbial activity. There are exceptions, where a pH of less than 5.5 was recorded in 11% of the sites in Tasmania, and a pH of greater than 7.5 in 24% sites in

Queensland. In NSW, the pH values are divided into two groups based on the two soil types: the Beneramba soils having a pH ranging from 6.0 to 7.0, and the Cookathama soils having a pH ranging from 7.3 to 8.5. In Victoria, the reference site was acidic, while the cropped sites were alkaline due to liming.

Except for one site in Tasmania, the EC values of all the sites in Tasmania and Victoria are relatively low and within acceptable limits (20 mS/m and below). In Queensland, approximately 36% of the sites had relatively high EC values, ranging from 36 to 94 mS/m. These high values in the cropped sites are in sharp contrast to the 8 reference sites, where the EC values ranged from 2.2 to 8.0 mS/m. In NSW, 50% of the sites also had relatively high EC values are an indication of the high rate of fertiliser applications, which can create a salinity problem.

Figure 5.4: The EC and pH of soils at 45 to 65 cm deep, from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.



In the subsoil (45 to 60 cm), soils in Tasmania tended to be acidic, and NSW soils tended to be alkaline. In Queensland, the pH values of the subsoils could be divided into two groups, with acidic to neutral soils in Bundaberg, and alkaline soils in Bowen, Gumlu and Gatton.

The EC values of almost all of the surveyed sites are relatively low, at 45-60 cm. There are a few exceptions, with high values at one site in NSW and two sites in Queensland (150, 140 & 80 mS/m, respectively), indicating salinity problems.

Soil microbial activities

Soil organisms are very sensitive to changes in soil conditions and management practices. Some of the important influences of soil organisms on nutrient recycling and soil processes are listed in **Table 5.1**. Soil microflora (bacteria and fungi) and microfauna (nematodes) are particularly sensitive to the quantity and quality of organic matter, the degree of soil disturbance and a whole range of management practices. Therefore, in this project, many quantitative laboratory analyses were based on assessing soil microflora and microfauna, (eg PL-FAME analysis, microbial biomass carbon analysis, nematode population count, and colony forming unit counts for bacteria and fungi).

Table 5.1 Influence of soil biota on soil processes in ecosystems (Hendrix *et al.* 1990)

	Nutrient cycling	Soil structure
Microflora (e.g. bacteria, fungi)	Catabolise organic matter Mineralise and immobilise nutrients	Produce organic compounds that bind aggregates Hyphae entangle particles onto aggregates
Microfauna (e.g. nematodes)	Regulate bacteria and fungal populations Alter nutrient turnover	May affect aggregate structure through interactions with microflora
Mesofauna (e.g. segmented worms, mites, small millipedes)	Regulate fungal and microfauna populations Alter nutrient turnover Fragment plant residues	Produce fecal pellets Create biospores Promote humification
Macrofauna (earthworms, large insects)	Fragment plant residues Stimulate microbial activity	Mix organic and mineral particles Redistribute organic matter and microorganisms Create biospores Promote humification Produce fecal pellets

These dynamic biological indicators could serve as a warning system for practices that affect soil resilience. Changes in other non-biological soil properties, such as total and labile carbon, total nitrogen, soil aggregation, compaction, water holding capacity, soil pH and electrical conductivity will also affect these biological indicators. Therefore, these microbiological indicators are particularly useful in providing a better understanding of changes in the soil conditions and ecosystem, by providing profiles of the microbial activity and biodiversity.

In general, reference sites had a higher microbial status than crop sites, regardless of the different methodology used at the three laboratories. This shows that the different methods used for determining soil microbial populations and activities are comparable and indicative of changes in the soil environment. Useful methods identified in this study include fluorescein diacetate hydrolysis (FDA), microbial biomass carbon (MBC), and PL-FAME analysis. **Figure 5.5** shows the close correlation between MBC (measured by P. Moody of Department of Natural Resources Qld) and microbial activity (based on FDA method by M. Stirling of Biological Crop Protection).

FDA is a measure of general microbial activity based on the degree of hydrolytic activity of various enzymes such as lipases, proteases, and esterases that are produced by microbes. It has been found to be a good indicator of suppressiveness of soils to soilborne plant pathogens, with negative correlation reported with *Pythium ultimum* (Chen et al. 1988) and *Phytophthora parasitica* and *Pyrenochaeta lycopersici* (Workneh et al. 1994).

PL-FAME analysis is based on the profile of fatty acid methyl esters (FAMEs) that are chemically derived from phospholipids extracted from microbes in the soil samples. **Figure 5.6** shows the close correlation between MBC (measured by P. Moody of Department of Natural Resources Qld) and microbial activity (based on PL-FAMEs method by C. Pankhurst, CSIRO).

Figure 5.5: The relationship between microbial biomass carbon and total microbial activities (FDA) of soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.

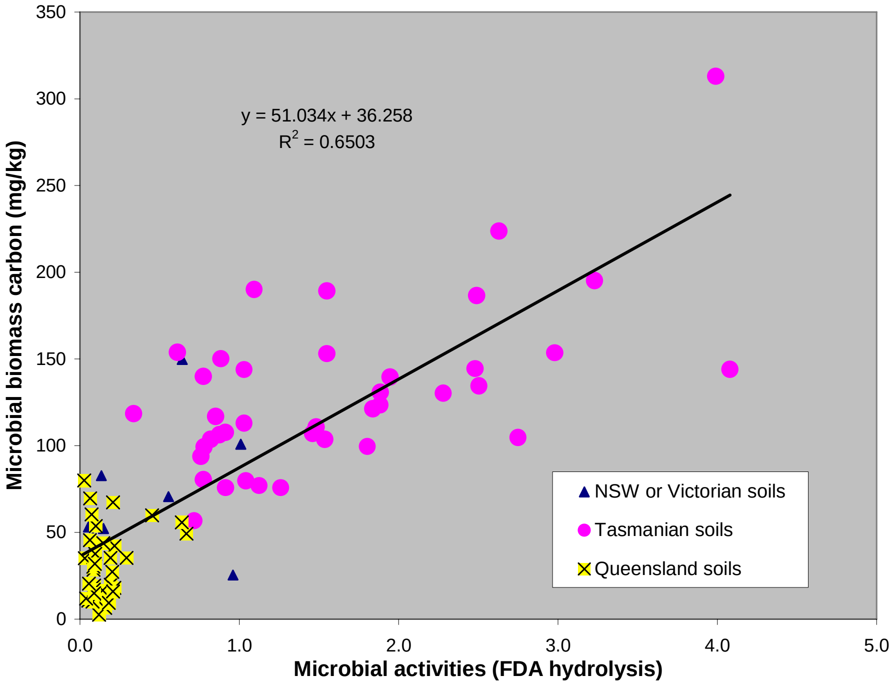
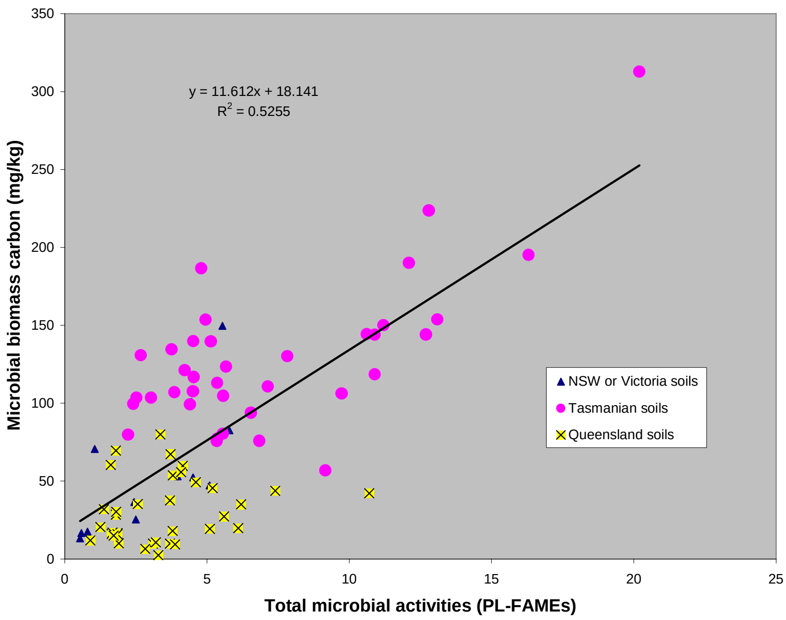


Figure 5.6: The relationship between microbial biomass carbon and total microbial activities (PL-FAMEs) of soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.



Unfortunately, apart from the general impact of disturbed soils (cropped sites) versus undisturbed soils (non-cropped pasture reference sites), the impact of the various crop management practices on these microbiological indicators cannot be properly assessed in this survey study. Long-term field trials of at least five years, involving replicated plots with different management practices, are required for comparative studies.

Soil nematodes

Soil nematode populations provide a useful reflection of changes in the soil environment (e.g. soil pores, soil water, and microbial populations). Soil nematodes can be divided into plant parasitic nematodes and free-living nematodes (**Table 5.2**).

Table 5.2 Free-living nematode and plant parasitic nematode types and population in soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria

	Nematode population (No. of nematodes / 200 g soil)									
	Saprophytic or free living nematodes				Plant parasitic nematodes					
Origin of soils	Fungal feeding nematode (FFN)	Bacteria feeding nematodes (BFN)	Omnivorous nematodes (Omniv)	Total free living nematodes (FFN + BFN + Omniv)	Root lesion nematodes (Lesion)	Total plant parasitic nematodes (Para)	%FFN	%BFN	FFN/ BFN	FLN/ Para
Queensland										
crop	246	1261	40	1548	44	21	14	85	0.2	1135
reference	1081	948	29	2058	191	400	53	46	1.6	260
NSW										
crop	562	737	3	1301	233	188	38	61	0.7	237
reference	310	210	53	573	370	370	54	26	3.2	5
Victoria										
crop	73	900	15	989	0	0	6	92	0.1	-
reference	1160	3950	85	5195	0	0	22	76	0.3	-
Tasmania										
crop	776	1363	14	2153	117	117	38	61	0.7	737
reference	3146	2320	168	5634	1100	1100	56	41	1.3	7

Free-living nematodes generally thrive in undisturbed soil, and decline in the cropped soils. They are beneficial to the soil ecosystem because they increase nutrient turnover and indirectly influence organic matter decomposition through their feeding and spreading of microbial decomposers. Many studies conducted elsewhere have shown that free-living nematode population determinations can be a quick, reliable and predictive method for detecting disturbances to the soil ecosystem (Blair et al. 1996).

Methods for nematode extraction and population determination are relatively simple and do not require expensive analytical equipment when compared to other methods for determining soil microbial activities. The diversity of the free-living nematodes (e.g. bacteria, fungal or predatory feeding nematodes) can also help to provide a more robust picture of soil microbial community.

Plant parasitic nematodes are highly susceptible to soil disturbance, and their population tended to be much lower in cropped soils compared to non-cropped reference soils. This is especially true with root lesion nematodes, as population densities were much lower in carrot sites than in reference sites. However, there may be exceptions with other nematodes, especially highly specialised plant parasitic nematodes such as root-knot nematodes and cyst nematodes, as their population can increase substantially in susceptible host crops and under favourable climatic conditions.

Soil tests for plant parasitic nematodes are highly recommended, especially when planting crops that are susceptible to damage or yield reduction by parasitic nematodes. Expensive soil fumigation or nematicide application for plant parasitic nematode control should be applied only when needed. Early detection of plant parasitic nematodes may also allow other non-chemical management practices to be implemented.

6. Technology Transfer Activities

6.1 News Releases

The following list summarizes the News Releases prepared to inform stakeholders about the project. General releases were sent to editors of local papers in major vegetable growing regions nationally, ABC Radio, QFVG News, Good Fruit and Vegetables, Queensland Country Life, The Land, The Weekly Times, Acres Australia, as well as Local Producer Association secretaries, science communicators, QDPI and CSIRO Media Officers and Vegetable Industry Development Officers. District focused releases such as those announcing grower forums were published regionally.

A comprehensive collection of where News Releases were published was not possible, but details of known publications are listed below each Release. Copies of the New Releases produced are in Appendix 5.

- **Towards healthier vege soils, 20/11/00**
  Measuring Soil Health, Queensland Fruit & Vegetable News, Jan 01
  Good Fruit and Vegetables, Jan 01

- **Healthy soils improve yield and sustainability, 27/6/01**
  Queensland Country Life
  Area News, Griffith
  Australian Farm Journal

- **Soil Health Forum for Bowen district, 7/2/02**
  The Advocate
  Bowen Independent
  ABC Radio – interviewed Jason Olsen

- **Soil Health Forum for Bowen and Bundaberg districts, 7/2/02**
  Forum into soil health, Queensland Fruit & Vegetable News, Feb 02
  Soil health data lacking, Queensland Country Life, 28 Feb 02

- **Soil Health Forum held in Bowen, 25/2/02**
  Bowen Independent
  Queensland Country Life
  NQ Register
  Mackay Bush Telegraph

- **Soil Health Forum for Bundaberg district, 4/3/02**
  Queensland Country Life, 7 March 02
  Bundaberg News Mail
  Daily Mercury

- **Soil Health Forum attracts growers to Bundaberg, 27/3/02**
  Bundaberg News Mail – sent a reporter/photographer to forum
  Daily Mercury

- ***A final News Release will be distributed nationally on completion of the Project Final Report.***