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

Dr Hoong Pung
Serve-Ag Research

Project Number: VG99057

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

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Hoong Pung *et al.*

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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.

1.2 Aims

This project was conceived as a result of a common interest in soil health shared by many scientists with a range of expertise, ranging from agronomy, soil chemistry, horticulture, microbiology, nematology, plant pathology, and soil physics. It also brought together a comprehensive range of laboratory skills and field expertise. Hence, this project is unique and yet ambitious in its attempt to thoroughly 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 yield.

Capsicum and carrot crops were used as benchmark crops for this feasibility study. These crops were selected because of their root-related problems such as sudden wilt of capsicum and the sensitivity of carrot quality to soil degradation. It was essentially a survey type study where soils were collected from many different cropped and reference sites in major production areas over two crop growing seasons.

The study in Queensland was confined to capsicum crops and soils, while carrot crops and soils were studied from Tasmania, New South Wales (NSW) and Victoria. Most of the sites surveyed in the project were in Queensland and Tasmania. Only a limited number of sites were surveyed in NSW and Victoria due to funding constraints.

2. General Materials & Methods

2.1 Capsicum & carrot crops

2.1.1 Capsicum - Queensland

Queensland is a significant producer of capsicums in Australia, with $49 million gross value product (GVP) of fruit in 1999/2000. Over half of Queensland's total GVP was from the Bowen-Burdekin region, whereas about one-fifth of the total GVP was from the Bundaberg-Burnett district. Thirteen percent of production occurred in the Gatton-Darling downs region. The soil health and plant health survey work for this project was conducted in all 3 regions, representing 93% of the gross value of capsicums produced in Queensland.

Many of the practices used for capsicum production in Queensland are detrimental to soil health. However, the high crop yields that are attained imply that the practices are beneficial for the crop in the short term. Normal land preparation can involve deep ripping, disc or tyne cultivation, rigid or spring tyne cultivation, harrowing and rotary hoeing. Application and incorporation of basal fertiliser, formation of beds, installation of trickle tubing and the laying of plastic mulch may be carried out in one operation by machinery specifically designed for this purpose. The raised bed that is formed facilitates good drainage along the plant row since excessive moisture can run into the lower inter-rows. Soil fumigants (e.g. methyl bromide or metham sodium) may be applied at bed formation, or administered through the trickle irrigation tubing prior to transplanting. Plastic mulch film is laid on the surface of the soil beds to manipulate soil temperature (black in winter, white in summer), reduce weed growth in the plant row, reduce soil evaporation, and avoid direct contact of fruit with soil. The use of trickle irrigation allows water to be applied directly to the root zone of the plant and the application of soluble fertilisers at any stage during the crop cycle.

The results of soil analysis and knowledge of the previous cropping history of the soil are major factors that determine the rate of basal fertiliser application by growers. In general, however, basal applications (in kg/ha of N:P:K) of 40-60:60-70:50-60 for low-P soils and 40-60:10-30:50-60 for high-P soils are usually administered prior to transplanting capsicum seedlings. Crops are normally established from nursery-grown seedlings, which are transplanted into field beds. Plant populations are commonly 27,000-35,000 per hectare. An adequate supply of N is important during pre-reproductive growth. Sap testing by rapid analytical techniques can be used to monitor the nutrient status of the crop and to correct any problems before yield or fruit quality are affected.

The quantity of water required to grow crops using trickle irrigation is dependent upon the climatic conditions of the locality and soil type, but is approximately 2-3 ML/ha for capsicums (Grattidge 1990). Most growers employ some form of irrigation scheduling; tensiometers are commonly used, particularly on smaller farms, whereas capacitance technology in a vertical profile (e.g. EnviroSCAN®) is used on larger farms. The time from transplanting seedlings into the field to harvest varies with cultivar and the temperature during the growing season, but is usually 14-16 weeks (Grattidge 1990). Mature green or coloured capsicum fruit are usually harvested weekly. Production of fruit is predominantly during autumn to spring in Bowen, all year round with production peaks in autumn and late spring to summer in Bundaberg, and through the summer to autumn period in south-east Queensland.

An example of declining soil health in capsicum crops grown in Queensland is 'sudden wilt'. This disease is usually associated with a complex of root organisms, primarily *Pythium* spp., *Fusarium* spp. and *Rhizoctonia* spp., although *Macorphomina* spp. may also be present. None of these fungi are thought to be solely responsible for 'sudden wilt', but given favourable conditions for soil pathogens, are thought to work together to cause the disease.

It is likely that management practices may have an important role in root health. An important objective of this study was to identify not only the status of soil and root health in Queensland's

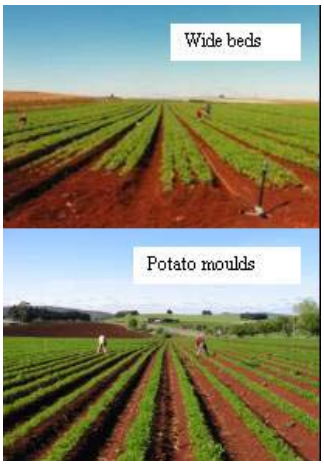
capsicum soils, but also to determine the management practices which give rise to these conditions.

2.1.2 Carrot - Tasmania

In Tasmania, carrots are produced for the fresh market and for processing. Nearly all of Australia's processing carrots for frozen vegetable products are grown in Tasmania. However, carrots grown for the fresh market have increased rapidly in recent years, and now account for more than 65% of the carrot crops in the state. Carrot export to Japan is mainly from Tasmania, where growing conditions are ideal for their preferred carrot type, Kuroda. Tasmanian carrots are also exported to south-east Asia and shipped to other major domestic markets in south-eastern Australia.

In Tasmania, a large number of vegetable growers produce carrots under contract as part of their rotation. Typical rotational crops include other vegetables, pyrethrum, poppies, potatoes and pastures. Two major processing and three major fresh market companies control production, along with a few small grower/packers. The major fresh market companies contract about 60 individual growers per year. Company-employed field officers supervise planting and harvesting operations, and assist in crop monitoring.

Almost all carrots are produced in the north-west coastal region of Tasmania. Carrots in Tasmania are mainly grown in Ferrosol soils (also known as krasnozems), which are high in clay and organic matter. Nantes and Kuroda are the main carrot types grown for fresh market. Crops in the survey were grown in 2.1 m wide beds with three double-plant rows or in 0.8 m wide potato moulds in a single double-plant row, depending on which fresh market companies they are produced for (**Photograph 1**). Due to the cool climate, carrots can be stored in the ground into winter. Carrots usually suffer increases in root rot with the onset of cool, wet weather in May. Soil fumigation is rarely used, and carrots are typically sown at intervals of three years or more in rotation with other crops or pastures.



Photograph 1: Carrots sown in wide beds (top) and potato moulds (bottom).

The main cultivation implements used include power harrows, ploughs, and agrow plough and bed formers, which are used to prepare seedbeds. Basal fertilisers consisting of nitrogen, phosphorus and potassium are applied before or during sowing. Except for one site with fixed overhead sprinklers, all crop sites in this study were irrigated with travelling irrigators, the most common form of irrigation in the region. Irrigation scheduling was only used at about 20% of the sites, where soil moisture was monitored (mostly with tensiometers).

Size, shape and appearance are critical for fresh market carrots, while appearance and shape are less important for processing-grade carrots that are used for processing into juice, frozen vegetables and canned vegetables. Carrot crops are established with direct seeding, usually with precision air-seeders. Seedling establishment is sensitive to soil management practices, seedbed preparation and soil moisture. As a root crop, carrots are susceptible to a range of soil related problems such as soil structural degradation and soilborne pathogens. This made it an ideal benchmark crop for this soil health study. The consistency in planting and management practices for carrot crops due to the contractual arrangements between growers and the major companies, helped to reduce variability in carrot varieties and the carrot crop management practices between growers. Growers under contract with two major fresh market companies produced approximately 90% of the Tasmanian carrot crops surveyed in this project.

2.1.3 Carrot - NSW

Carrots are grown on medium clay loam soils in and around Griffith. The major production areas are located south-west of Griffith, between the townships of Griffith and Darlington Point. All carrot crops are furrow irrigated, using 90 cm beds, and a slope of 1:1000 to 1:1500. Most soils used for carrot production are Wunnamurra clay loams (grey) or Yooroobla clay loams (grey/yellow). These soils tend to self-mulch and have a deep A horizon (30 cm or more). High water tables can be a problem in some locations, but are less of an issue closer to the Murrumbidgee River (which runs through Darlington Point).

The main cultivation implements include power harrows and disc ploughs, and bed shapers and formers are used to prepare the final hill prior to planting. The ground can be worked 3-4 times prior to planting, with discing followed by power harrows, and finally bed shapers. Some growers also cultivate furrows in between each watering to even up the rate of infiltration down the furrows. Gypsum and composted poultry manure or feedlot manure are sometimes used, particularly if a block has been laser levelled recently. Cut areas tend to be top-dressed with some form of organic matter to improve texture and workability of the soil.

Initial irrigation tends to entirely wet the profile and bed to ensure even germination of carrots. This irrigation tends to be the largest. Subsequent irrigations are often alternate row irrigations, keeping every 2nd row dry. This is to avoid over watering, which can lead to anaerobic soil conditions, causing root rots.

Western Red (imperator) type carrots comprise 80% of the crops. Nantes carrots do not perform well on the heavier soil, and are more prone to breaking at harvest on the clay soils. Carrots for the fresh market are generally harvested when the carrots reach 18-20 cms in length. Carrots for processing (juicing) are left longer to increase yield. Soils are relatively free of stones, etc., that may cause misshapen carrots. The most common cause of misshapen carrots is planting density, which is very high in a single row on a bed. Few growers use precision seeders, so uneven populations often result in twisted carrots, and size variability in the row.

2.2 Sampling protocol

The area of a trial site was fixed, although the size of each site was not less than 20 m x 20 m. Two types of sites were sampled:

- Cultivated land with a growing crop (**crop site**)
- Uncultivated land, preferably in pasture (**reference site**)

Where possible, each reference site was adjacent to a crop site, although this linkage was not possible in all cases. The number and locality of sites is shown in **Table 2.1**.

Soil profiles of the sites were also described at the discretion of the soil surveyor in Queensland and Tasmania, and all locations of the surveyed sites were recorded using the global positioning system (GPS) for future reference in all states (**Photograph 2**).

Photograph 2: Global positioning system used to record site location for future reference

Table 2.1 - Synopsis of the number and locality of sites sampled from each state

State (Cooperator)	No. of crop sites sampled	No. of reference sites sampled	Locality	Soil
Queensland (Jason Olsen, Steve Jackson)	36	8	Gatton Bundaberg Bowen Gumlu	Black earth (Vertosol) Yellow podzolic (Kurosol) Black earth (Vertosol) Grey hard-setting
Tasmania (Hoong Pung, Pam Cox, Bill Cotching)	35	5	Forth	Clay loam (Red Ferrosol)
NSW (Mark Hickey, Jane Hulme)	6	2	Griffith	Grey self-mulching clay (Vertosol) Cobram sandy loam (Red Kandosol)
Victoria (Bill Ashcroft)	3	1	Robinvale	Fine sandy loam (Tenosol)

2.3 Site selection, soil sampling & field assessments

To reduce the possible variabilities in the data set, the crop sites selected had similar crop cultivars, irrigation practice, and time of growing season within the region. The crop sites covered a wide variation of management styles (e.g. ± fumigation) and cropping history. The planting period was also consistent within regions. Pasture was preferred to woodland for the undisturbed reference sites.

Penetrometer readings were taken to a depth of 60 cm at each **crop site** to measure presence of a compaction layer. No penetrometer readings were taken at the **reference sites**, since the issue of a hard pan from cultivation practice was not relevant. Nine penetrometer readings were taken from each site (3 subplots x 3 readings). In Queensland, the penetrometer readings were taken from bed centres under plastic mulch, which were moist from irrigation. In the southern states, penetrometer readings were taken during the carrot production season when soil was wet after irrigation. Soil penetration resistance, expressed in kPa, was taken at 15 mm intervals to a depth of 600 mm using a mechanical cone soil penetrometer. Three sets of penetration resistance measurements were compiled for data analysis:

- Soil depth where the first maximum penetrometer value was taken as a measure of the depth of any hard pan
- Average penetration resistance at 0-150 mm
- Average penetration resistance at 150-300 mm

Gravimetric soil moisture determinations were made to a depth of 60 cm at each **crop site**. At each site, gravimetric moisture was determined from a total of 3 cores (1 core adjacent to each of the 3 yield subplots). The moisture determinations were made at 0-15, 15-30, 30-45, and 45-60 cm depth intervals. Therefore, average gravimetric moisture was determined for 12 (3 cores x 4 depths) soil samples at each crop site. For each yield subplot, the core extracted for gravimetric water content was in the midst of the 3 profiles where penetrometer readings were taken:

e.g. **X O X**
X for sampling of carrot sward crops

or **X O X X** for sampling of capsicum row crops, where 'X' is a penetrometer reading and 'O' is the profile sampled at 0-15, 15-30, 30-45, and 45-60 cm for gravimetric moistures.

Since penetrometer readings were not taken at the reference sites, moisture determinations were not required at these sites. Hand augurs were used to extract soil cores for moisture determination.

The sample depth for subsoil analyses was dependent upon the location of the interface of A and B horizons, as follows:

- If no B horizon, or a gradational texture change, then the sample from 45-60 cm depth was taken.
- If the soil had an A/B texture contrast <45 cm from the soil surface, then the sample from the top 15 cm of the B horizon was taken.

Assuming a gradational texture change in the soil, the core adjacent to each yield subplot at each crop site was sampled from the 45-60 cm depth, labelled separately, and sent for subsoil pH, EC, and Cl analysis. For reference sites, soil was sampled at the 45-60 cm depth from 3 cores, and labelled separately. All samples were sent to the Department of Natural Resources (DNR) laboratory for pH, EC and Cl analysis. Therefore, 3 samples at the 45-60 cm depth from each crop site and reference site were taken.

In Tasmania, soil at each site was also rated using a soil structure score that was developed for use on Ferrosol soils in Tasmania, as shown in Appendix 4.

2.4 Yield data from the CROP SITE

An estimate of the yield of the crop was obtained from each crop site. In Queensland, yield data from the capsicum sites were taken from 2-5 harvests from 3 x 10 plant plots within the trial area. The 10 plants in each yield subplot were marked with wire stakes and pink flagging tape at the time of soil sampling.

In the southern states, carrot yield data were taken from a single harvest from 3 x 1m^2 subplots within the trial area. In Tasmania, carrots from each site were sorted into 'marketable' and 'reject' according to the fresh market carrot grading system. Four plant rows in two 0.8 m wide beds (potato moulds), or six plant rows in the 2.1 m wide beds were assessed. All yields were then adjusted to six plant rows as a standard for comparison. In general, carrot yield from the two types of beds were similar. Carrots in the reject category were further sorted into diseased, misshapen, forked, undersized, bolters, insect damage, and others. The percentage packout rate, an indicator of carrot quality, was calculated by dividing the number of marketable carrots with the total number of carrots and multiplying by 100. In NSW and Victoria, the total carrot numbers and weight from each site were recorded. As the carrots in NSW and Victoria were produced for juicing, the packout rate was 100% in the crops.

2.5 Soil analysis for physical, chemical & biological properties

Laboratories at DNR, Biological Crop Protection, and CSIRO conducted chemical analysis and biological assessments for nematodes, microbiological activities and population, microbial biomass carbon, and organic carbon **(Table 2.2)**. For PL-FAME analysis, the soil samples were sent to the CSIRO laboratory in South Australia with mandatory phytosanitary certificates.

For the crop sites, about 5 L of soil was sampled at the 0-15 cm depth with trowels, from about 30 locations within each site. For the reference sites, augurs or spades were used to collect the 0-15 cm samples, since trowels were impractical. The soil was kept cool, at around 20ºC, until shipment to the laboratories. The quantities of soil shipped to DNR, Biological Crop Protection and CSIRO were 0.2 L, 2.5 L and 0.2 L, respectively.

Table 2.2 - Details of the measurements made on topsoil samples (0-15 cm) by the three laboratories in the project

Laboratory (Cooperator) **Type of Test** ***Data generated***	**Methods**
Biological Crop Protection Pty Ltd (Marcelle Stirling)	
Nematode test *Bacterial-feeding nematodes (BFN)* *Fungal-feeding nematodes (FFN)* *Omnivorous nematodes (Omniv)* *Total free-living nematodes (FLN)* *Plant parasitic nematodes (Para)*	Nematodes were extracted from 3 replicates of 200 mL sub-samples using the Baermann tray technique (Whitehead & Hemming 1965) for four days. Both free-living and plant-parasitic nematodes were counted, with free-living nematodes being separated into fungal-feeders, bacterial-feeders, and omnivores. The plant parasitic nematodes were separated into genera.
Colony forming unit counts *Total bacteria (Total bact)* *Gram-positive bacteria (Total G+Bacteria)* *Fluorescent* Pseudomonas *(Fluo. Pseu)* *Total Fungi* Actinomycetes *(Actino)*	Populations of culturable microorganisms were measured on various media using a combination of procedures including serial dilution (Stirling et al. 1995) the plate dilution frequency technique (Harris & Sommers 1968) and the most probable number technique ((Meynell & Meynell 1970).
Fluorescein diacetate test *Total microbial activity (FDA)*	Total microbial activity was determined by measuring the rate of hydrolysis of fluorescein diacetate (FDA) by microbial enzymes in soil (Schnürer & Rosswall 1982).
CSIRO (Clive Pankhurst)	
PL-FAME analysis *Total bacteria* *Gram positive bacteria* *Gram negative bacteria* *Fungi* *Mycorrhizal fungi (VAM)* *fungi:bact. ratio* *Total microbial activites (Total PL-FAMEs)*	The composition of the soil microbial community was determined by PL-FAME analysis of the profile of fatty acid methyl esters (FAMEs) chemically derived from phospholipids (PL) extracted from the soil samples (Zelles 1999; Pankhurst et al. 2001). Brieftly, twelve grams of soil from each field replicate was extracted in a chloroform:methanol:phosphate buffer. The extracted phospholipids were then subjected to acid methanolysis, and the resulting phospholipid fatty acid methyl esters (PL-FAMEs), which were re-dissolved in hexane for gas chromatographic analysis. The PL-FAMEs were separated by using Hewlett Packard HP gas chromatography fitted with a flame ionisation detector and a silica capillary column. The FAME peaks were identified using a computer program, and the peak areas were normalized against the internal standard and expressed as µg g soil^{-1}. Data on up to 80 different fatty acids was routinely obtained in the PL-FAME profiles of individual soil samples. PL-FAMEs of interest were those that could be used as biomarkers for different microbial functional groups.

Table 2.2 Details of the measurements made on topsoil samples (0-15 cm) by the three laboratories in the project (continued)

Laboratory (Cooperator) Type of Test *Data generated*	Methods
DNR-Qld (Phil Moody)	
Microbial biomass carbon microbial biomass carbon (MBC)	Microbial biomass C was estimated by the microwave irradiation method (Wang et al. 2001). Briefly, duplicate field moist soil samples were weighed into extraction vessels, and one duplicate was microwave irradiated to lyse microbial cells. Soluble organic carbon was then extracted with 0.5 M K_2SO_4 from both the microwaved and non-microwaved samples. The difference in soluble organic carbon levels was expressed as mg C/kg soil, and is a measure of the microbial biomass carbon.
Accessible organic carbon *Carbon fraction 1 (C1)* *Carbon fraction 3 (C3)*	Microorganisms break down organic (C-containing) compounds in soil organic matter to produce energy for metabolic reactions and growth. The breakdown process involves oxidation reactions with the production of CO_2 gas. These oxidation reactions can be simulated by oxidising soil organic carbon with oxidising agents such as potassium permanganate - as the concentration of the oxidising agent increases, more resistant organic compounds are oxidised. Two concentrations of the oxidising agent potassium permanganate were used in this study - 33 mM (designated C1) and 333 mM (designated C3). Methodology used was as described by Blair et al. (1995).
Total organic carbon and total nitrogen *Total carbon (Total C)* *Total nitrogen (Total N)* *C:N ratio*	Total organic C was determined on acid pre-treated samples by combustion in a Leco C-N Analyser with total N determined simultaneously by infrared detection (Method 6B3 in Rayment & Higginson (1992)). The C:N ratio was determined from total organic C and total N figures.
Soil pH & EC *pH and EC at 0-15 cm* *pH and EC at 45-60 cm*	Soil pH and EC were determined on 1:5 soil/water suspensions (Methods 4A1 and 3A1, respectively, in Rayment & Higginson (1992)).
Aggregate stability *% particulates of greater than 0.5 mm (% Aggregate stability)*	Aggregate stability was measured by immersion and gentle agitation of soil samples (in field moist state) on a nest of sieves. The % aggregates > 0.5 mm was calculated after correction for the primary particle contents.

2.5 Questionnaire

In a survey questionnaire, growers were asked to supply field information relating to cropping history, soil cultivation and management practices, and their perception of the status of soil health at the crop sites. The crop specialist conducting the survey also provided field information relating to the status of the crop health at each site, which was included with the questionnaire. The questionnaire form, consisting of 35 questions, used for the capsicum/carrot sites is included as **Appendix 1**.

2.6 Statistical analysis

Queensland & Tasmanian soils

A matrix of all possible pair-wise simple correlation coefficients was derived. Variables in the grower survey that were not continuous (e.g. questions which required a yes/no response [dummy variables] or rating questions for which the responses were confined to just 2 values) were not included in this correlation analysis. Correlation coefficient values in the matrix which exceeded the necessary value for significance at P=0.05 were considered of interest and worthy of further investigation.

Queensland soils

A step forward multiple linear regression analysis procedure was used to determine the relationship between weight of marketable fruit (taken to be the response variable in the regression model and reflecting plant health) and the other measurements from the soil analysis and the grower survey (explanatory variables reflecting soil health). The final regression model was accepted at the step for which the next variable to be selected was not significant at P=0.05.

As an alternative regression modelling approach to confirm (or otherwise) the results of the stepwise procedure, a 'best subset regression screening' procedure was conducted. As required by this procedure, only the variables considered most relevant to the weight of marketable fruit (plant health) were selected.

Apart from the 'best subset regression screening' procedure, which was conducted using Statistix for Windows™ (Analytical Software Tallahassee, Florida), all other statistical analyses and procedures were completed using Genstat™ (GenStat 2000).

Tasmanian soils

A multiple regression analysis was conducted using StatGraphics Plus Version 4, to determine the correlations between carrot yield and quality with other selected variables. The other selected variables consisted of soil analysis data, field assessments data and other information from the growers' survey, which were found to have significant correlation (P=0.05) in the initial matrix of all possible pair-wise simple correlation coefficients. The final regression model was accepted at the step for which the next variable to be selected was not significant at P=0.05.

3. Capsicum soils, Queensland

3.1 Results

3.1.1 Depth to the hard pan

Depth to the first maximum penetrometer value was taken as an informative measure to the depth of any hard pan, following advice by Principal Soil Scientist, Des McGarry. It was deemed that the penetrometer readings were taken at field capacity because:

1) Observation of the soil cores taken from the sites revealed a uniform moisture distribution.
2) Frequent application of irrigation water through trickle irrigation tubing under plastic mulch provided a low risk of developing a well defined wetting front in the soil prior to measurement.
3) By preventing evaporative loss and inhibiting the penetration of rainfall, plastic mulch led to uniform soil moisture conditions.

Depth to the first maximum penetrometer value was taken as an informative measure to the depth of any hard pan (**Table 3.2)**, and this variable was used in the correlation analyses. Values ranged between 240 and 600 mm, with a mean of 487 mm.

Table 3.2 - Depth to the first maximum penetrometer value at each crop site

Site	Depth to maximum value (mm)	Site	Depth to maximum value (mm)
Q1	600	Q19	585
Q2	585	Q20	600
Q3	360	Q21	495
Q4	330	Q22	420
Q5	240	Q23	570
Q6	240	Q24	315
Q7	555	Q25	435
Q8	330	Q26	570
Q9	255	Q27	435
Q10	585	Q28	495
Q11	555	Q29	495
Q12	555	Q30	495
Q13	600	Q31	525
Q14	570	Q32	345
Q15	585	Q33	435
Q16	480	Q34	600
Q17	600	Q35	600
Q18	495	Q36	600

The value at each site is the mean of 9 penetrometer readings. Sites Q1-13, Q14-33, or Q34-36 were located at Bowen/Gumlu, Bundaberg, or Gatton, respectively.

3.1.2 Nutrient management

The grower questionnaire allowed us to calculate the amount of each element applied from fertiliser (**Table 3.3**).

A ranking of the elements applied is as follows: K>Ca>N>S>P>Mg>Fe>Cl>Cu, Mn>B, Mo. The large amount of applied Ca reflected the fact that the addition of lime to the soil up to 6 weeks before planting the crop was included in the calculation of nutrients. At the majority of sites, the micronutrients Zn, Cu, Fe, B, Mo, and Mn were not applied.

Table 3.3 - The total amount of individual elements applied as fertiliser (basal and by fertigation) for the capsicum crop grown at each site sampled in Queensland

Site	N	P	K	S	Ca	Mg	Zn	Cu	Fe	B	Mo	Mn	Cl
Q 1	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 2	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 3	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 4	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 5	140.1	60.0	185.4	47.1	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 6	140.1	60.0	185.4	47.1	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 7	99.1	25.7	77.0	79.3	21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8
Q 8	99.1	25.7	77.0	79.3	21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8
Q 9	101.6	25.7	117.9	94.8	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8
Q 10	84.3	46.4	116.4	112.6	121.4	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 11	164.0	45.0	171.2	3.6	66.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 12	115.4	71.3	117.6	4.9	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 13	115.4	71.3	117.6	4.9	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q14	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q15	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q16	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q17	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q18	102.4	56.5	74.5	35.0	54.2	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Q19	69.9	61.4	80.5	43.9	49.6	2.0	0.0	0.1	0.7	0.0	0.0	0.1	0.0
Q20	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q21	118.8	15.2	239.8	49.1	97.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q22	156.4	94.5	157.5	71.3	70.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q23	-	-	-	-	-	-	-	-	-	-	-	-	-
Q24	223.8	136.7	304.4	537.4	1651.1	126.3	0.0	0.7	4.5	0.0	0.0	0.5	0.0
Q25	179.9	123.5	217.0	497.9	1611.9	116.6	0.0	0.7	4.5	0.0	0.0	0.5	0.0
Q26	163.9	20.1	191.6	1.6	86.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q27	171.5	127.1	190.5	22.8	38.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q28	91.6	140.8	405.7	153.9	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q29	91.6	140.8	405.7	153.9	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q30	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q31	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q32	87.5	18.3	252.5	63.3	71.8	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q33	156.4	94.5	157.5	71.3	70.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q34	121.1	112.5	100.0	64.1	197.3	17.5	2.5	1.4	20.5	0.3	0.0	1.8	0.0
Q35	121.1	112.5	100.0	64.1	197.3	17.5	2.5	1.4	20.5	0.3	0.0	1.8	0.0
Q36	77.8	72.5	125.0	37.2	21.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	**126.2**	**70.2**	**171.0**	**73.4**	**163.2**	**11.2**	**0.6**	**0.3**	**3.6**	**0.0**	**0.0**	**0.3**	**1.4**

Sites Q1-13, Q14-33, or Q34-36 were located at Bowen/Gumlu, Bundaberg, or Gatton, respectively.

3.1.3 Other management practices

The quantity of irrigation water applied to each capsicum crop (estimated by growers) ranged from 1 - 3.5 ML/ha, with an average of 2.5 ML/ha (**Table 3.4**). For the crop measured in the survey at each site, the average number of total passes with a cultivation implement was 4.1 (range 2-9), whereas the average number of passes with a rotary hoe or power harrows was 1.7 (range 1-3).

An intensive cropping program was applied at most sites. The average number of solanaceous crops grown in the preceding 5-year period (3.8, range 1-11), soil fumigations used (2.3, range 0-11), fallows employed (0.8, range 0-4), and green manure crops grown (1.3, range 0-6) are presented in **Table 3.4**. Furthermore, of the 36 capsicum sites surveyed, a fumigant (either metham sodium or methyl bromide) was applied to the soil at 19 sites prior to planting the seedlings; viz. a soil fumigant was applied to 53% of the crop sites surveyed. Of the 19 sites at which a soil fumigant was applied, metham sodium was used at 14 sites.

Table 3.4 - Various management practices employed at the Queensland capsicum sites

Site	Tot irrig used for crop (ML/ha)	Tot no. passes cultiv equip for crop	Tot no. passes rotary hoe /power harrows for crop	No. solanaceous crops grown in past 5 yr	No. times a fumigant used in past 5 yr	No. times site fallowed in past 5 yr	No. times a green manure crop grown in past 5 yr	Fumigant applied prior to crop (rate)¶
Q 1	3	6	1	4	2	0	1	NaM (200)
Q 2	3	6	1	2	3	3	0	NaM (200)
Q 3	3	6	1	3	4	2	0	NaM (200)
Q 4	3	6	1	3	2	1	0	NaM (200)
Q 5	3	7	1	1	1	2	2	NaM (800)
Q 6	3	7	1	1	1	0	0	NaM (800)
Q 7	3	3	1	4	4	0	5	NaM (130)
Q 8	3	3	1	4	4	0	5	NaM (130)
Q 9	2.5	3	1	4	3	1	4	NaM (300)
Q 10	2.5	9	N/a	4	0	0	5	-
Q 11	1.7	4	2	5	0	0	1	-
Q 12	3	N/a	1	4	1	0	1	NaM (?)
Q 13	3	N/a	1	1	1	0	0	NaM (?)
Q14	2	2	2	5	0	2	0	-
Q15	2	3	3	7	1	0	0	-
Q16	1.5	2	2	3	0	4	0	-
Q17	1.5	2	2	3	0	4	0	-
Q18	2	3	1	2	2	0	0	-
Q19	2.5	5	2	3	0	4	2	-
Q20	2.5	5	2	7	3	0	3	-
Q21	2.5	2	2	1	1	0	0	-
Q22	2.5	3	2	2	1	1	0	-
Q23	2.5	2	1	11	11	0	0	MBr (245)
Q24	2	3	1	1	1	0	0	NaM (?)
Q25	2	4	1	5	5	0	0	NaM (?)
Q26	2.5	3	2	1	0	0	0	-
Q27	3.5	2	1	7	7	3	0	MBr (245)
Q28	2.5	4	3	4	7	0	6	MBr (123)
Q29	2.5	4	3	5	7	0	6	MBr (123)
Q30	2.5	3	2	7	3	0	3	NaM (74)
Q31	2.5	5	2	7	3	0	3	-
Q32	2.5	3	2	4	4	0	0	-
Q33	2.5	3	2	2	2	0	0	MBr (245)
Q34	2.5	4	3	3	0	0	0	-
Q35	2	4	3	3	0	0	0	-
Q36	1	7	1	3	0	0	0	-
Mean	**2.5**	**4.1**	**1.7**	**3.8**	**2.3**	**0.8**	**1.3**	**-**

Sites Q1-13, Q14-33, or Q34-36 were located at Bowen/Gumlu, Bundaberg, or Gatton, respectively.
¶The fumigants applied prior to transplanting the capsicum seedlings of the crop that we measured included metham sodium (NaM, applied in L/ha) or methyl bromide (MBr, applied in kg/ha).

3.1.4 Some measures of soil health

Some selected measures of the health of the soil are presented in **Table 3.5**. The number of omnivorous nematodes and the total number of free-living nematodes was relatively higher in the Vertosol soils of the Gatton district than in soils from the other districts (**Table 3.5**). Total PL-FAMEs tended to be higher in the Black Vertosol and Black Dermosol soils of the Bowen district than in the other soils sampled. Application of a soil fumigant prior to cropping (**Table 3.4**) appeared to have little effect on any of the soil health measures presented in **Table 3.5**.

Table 3.5 - Some measures of the health of the soil at the Queensland capsicum crop sites

Site	Omnivorous nematodes (per 200 mL soil)	Total free - living nematodes (per 200 mL soil)	Total microbial activity (µg FDA/g/min)	Fluorescent Pseudomonads (Log_{10} cfu/g soil)	Microbial biomass C (mg/kg)	C_1 (g/kg)	Total bacteria (µg/g)	Fungi (µg/g)	VAM (µg/g)	Total PL-FAMEs (µg/g)
Q1	0	1,265	0.10	5.22	53.7	0.78	1.11	0.06	0.12	3.80
Q2	2	2,074	0.09	3.59	19.4	0.66	1.67	0.05	0.17	5.10
Q3	0	3,160	0.03	4.59	35.1	0.95	2.20	0.08	0.16	6.20
Q4	0	1,526	0.06	4.22	45.5	0.63	1.61	0.11	0.14	5.20
Q5	1	2,546	0.19	5.22	19.8	1.10	1.95	0.18	0.17	6.10
Q6	1	1,732	0.22	5.22	42.2	1.19	3.64	0.18	0.20	10.70
Q7	2	938	0.14	4.81	9.9	0.59	1.08	0.10	0.08	3.10
Q8	11	218	0.17	5.22	9.9	0.68	1.23	0.10	0.10	3.70
Q9	2	3,412	0.15	6.3	43.8	1.16	2.36	0.19	0.19	7.40
Q10	55	2,485	0.20	4.39	27.3	0.79	1.70	0.28	0.17	5.60
Q11	0	1,265	0.05	5.59	10.7	0.79	1.07	0.08	0.12	3.20
Q12	0	960	0.10	5.39	37.6	0.69	1.20	0.08	0.13	3.70
Q13	1	751	0.09	4.06	28.5	0.45	0.55	0.02	0.05	1.80
Q14	5	900	0.12	3.81	2.5	0.86	0.94	0.03	0.08	3.29
Q15	12	1,102	0.16	3.18	6.5	0.89	0.98	0.03	0.07	2.83
Q16	8	2,073	0.29	4.59	35.3	1.01	0.85	0.02	0.07	2.57
Q17	15	2,237	0.45	3.74	59.8	1.16	1.31	0.03	0.09	4.15
Q18	3	2,253	0.13	3.53	16.2	1.07	0.62	0.00	0.00	1.65
Q19	3	463	0.67	0	49.3	1.51	1.39	0.05	0.09	4.61
Q20	1	1,451	0.08	3.22	10.1	0.76	0.55	0.03	0.04	1.90
Q21	2	582	0.14	3.59	16.6	0.34	0.59	0.00	0.02	1.86
Q22	0	475	0.18	0	9.4	0.81	1.11	0.04	0.07	3.88
Q23	0	285	0.04	3.53	11.9	0.39	0.31	0.00	0.00	0.90
Q24	3	658	0.22	2.93	18.0	0.94	1.37	0.02	0.04	3.79
Q25	1	436	0.19	3.81	35.3	0.63	0.82	0.02	0.02	2.57
Q26	0	1,020	0.64	0	55.8	1.01	1.50	0.03	0.04	4.09
Q27	0	1,392	0.09	3.85	17.0	0.47	0.57	0.02	0.01	1.68
Q28	0	1,910	0.08	4.39	30.3	0.86	0.72	0.01	0.01	1.81
Q29	0	2,180	0.21	2.93	15.9	0.90	0.68	0.02	0.01	1.85
Q30	2	332	0.09	0	15.0	0.93	0.53	0.02	0.02	1.72
Q31	1	341	0.06	0	20.5	0.66	0.40	0.01	0.01	1.25
Q32	4	434	0.06	0	69.6	0.43	0.54	0.02	0.02	1.80
Q33	4	789	0.09	3.59	31.9	0.73	0.50	0.02	0.01	1.38
Q34	147	2,955	0.03	3.39	80.0	1.37	1.24	0.04	0.12	3.36
Q35	466	1,806	0.07	3.06	60.4	1.03	0.66	0.00	0.06	1.62
Q36	670	7,320	0.21	4.08	67.3	1.33	1.35	0.06	0.11	3.72
Mean	**39.5**	**1,548**	**0.16**	**3.47**	**31.1**	**0.85**	**1.14**	**0.06**	**0.08**	**3.44**

Sites Q1-13, Q14-33, or Q34-36 were located at Bowen/Gumlu, Bundaberg, or Gatton, respectively.

3.1.5 Matrix of all possible pair-wise simple correlation coefficients

Correlation coefficient values greater than 0.36 in the matrix of all possible pair-wise simple correlation coefficients were significant at *P*=0.05. These values are presented in bold type in **Appendix 3**, and are considered of interest and worthy of further investigation.

In general, data from within individual laboratories were well correlated. For example, for the Biological Protection laboratory, bacterial-feeding nematodes were positively correlated with fungal-feeding nematodes, omnivorous nematodes, total free-living nematodes, or fluorescent pseudomonads. From the CSIRO laboratory, fungi were positively correlated with Gram-negative bacteria, Gram-positive bacteria, total bacteria, total PL-FAMEs, or mycorrhizae (VAM). Data from the DNR laboratory followed a similar trend, with C_1 positively correlated with C_3, C:N ratio, total C, or total N.

The $\log_{10}$ of the number of colony forming units of fluorescent pseudomonads was correlated with a range of other biological measures from both the Biological Crop Protection and CSIRO laboratories, including bacterial-feeding nematodes (r=0.51), fungi (r=0.54), Gram-positive bacteria (r=0.41), PL-FAME (r=0.37), total bacteria (r=0.39), total free-living nematodes (r=0.40), and VAM (r=0.52).

Labile carbon C_1 was positively correlated with bacterial-feeding nematodes, fungal-feeding nematodes, total free-living nematodes, total microbial activity measured by fluorescine diacetate hydrolysis (FDA), Gram-negative bacteria, Gram-positive bacteria, total bacteria, total PL-FAMEs and VAM (**Table 3.6**). However, C_3 was positively correlated with only FDA or Gram-negative bacteria, whereas total C was correlated with just FDA.

A comparison of potential soil health indicators from the matrix of all possible pair-wise simple correlation coefficients revealed that bacterial-feeding nematodes, C_1, and mycorrhizae were correlated with the greatest number of the other soil health parameters (11, 9, and 9 parameters, respectively, **Table 3.6**).

Table 3.6 - Comparison of potential soil health indicators which were significant in the matrix of all possible pair-wise simple correlation coefficients for the information collected from the capsicum sites in Queensland

BFN	C_1	VAM	TotBac	Fluo	TotFLN	Fungi	PLFAME	FFN	MBC	Omniv	FDA
C_1	BFN	BFN	BFN	BFN	BFN	BFN	BFN	BFN	FDA	BFN	C_1
FFN	FDA	C_1	C_1	Fungi	C_1	Fluo	C_1	C_1	FFN	FFN	MBC
Fluo	FFN	Fluo	Fluo	Gpos	FFN	Gneg	Fluo	MBC	Omniv	MBC	
Fungi	Gneg	Fungi	Fungi	PLFAME	Fluo	Gpos	Fungi	Omniv	TotFLN		
Gneg	Gpos	Gneg	Gneg	TotBac	MBC	PLFAME	Gneg	TotFLN			
Gpos	PLFAME	Gpos	Gpos	TotFLN	Omniv	TotBac	Gpos				
Omniv	TotBac	PLFAME	PLFAME	VAM	VAM	VAM					
PLFAME	TotFLN	TotBac	VAM								
TotBac	VAM	TotFLN									
TotFLN											
VAM											
11	**9**	**9**	**8**	**7**	**7**	**7**	**6**	**5**	**4**	**3**	**2**

The measures listed within each column were positively correlated at *P*=0.05 with the parameter in the column heading. An explanation of the codes used in the matrix is as follows: **BFN** = number of bacterial feeding nematodes per 200 mL soil; **C1** = g carbon fraction 1 per kg soil; **FDA** = total microbial activity as measured by µg fluorescine diacetate hydrolised/ g/ min; **FFN** = number of fungal-feeding nematodes per 200 mL soil; **Fluo** = $\log_{10}$ colony forming units of fluorescent pseudomonads per g dry soil; **Fungi** = fungi (µg/ g soil) as determined by PL-FAMEs; **Gneg** = Gram-negative bacteria (µg/ g soil) as determined by PL-FAMEs; **Gpos** = Gram-positive bacteria (µg/ g soil) as determined by PL-FAMEs; **MBC** = microbial biomass carbon (mg C/kg soil); **Omniv** = number of omnivorous nematodes per 200 mL soil; **PLFAME** = total phospholipid fatty acid methyl esters ((µg/g soil); **TotBac** = total bacteria (µg/g soil) as determined by PL-FAMEs; **Tot FLN** = number of free-living nematodes per 200 mL soil; **VAM** = total mycorrhizae (µg/g soil) as determined by PL-FAMEs;

There was a positive relationship between weight of marketable fruit and the ratio of C_1 to total C in the soil (r=0.40), applied N (r=0.46), pH at 45-60 cm (r=0.38), or total number of passes with an implement (r=0.48). Conversely, this yield parameter was negatively correlated with the C:N ratio of the soil (r=-0.37), and to the total number of passes with a rotary hoe/power harrow (r=-0.39).

The number of solanaceous crops and soil fumigations in the past 5 years were positively correlated (r=0.43), whereas the number of solanaceous crops and PL-FAME (r=-0.47), total bacteria (r=-0.49), or total parasitic nematodes (r=-0.43) was negatively correlated.

The rating for cloddiness was correlated with the electrical conductivity (EC) at depths of both 0-15 and 45-60 cm. The higher the EC measured in the soil, the more the grower rated their soil as being cloddy with big chunks, dusty and powdery.

The average weight of an individual marketable fruit was correlated with the rating for the overall appearance (r=0.46), and was also correlated with the rating for the health of the foliage (r=0.50). The ratings for crop appearance and foliage were also highly correlated with each other (r=0.74). However, neither the crop appearance nor foliage ratings were correlated with the total weight of marketable fruit harvested from the site. The average weight of a marketable fruit was also negatively correlated with the biological parameters of fluorescent pseudomonads (-0.38) or fungi (-0.42).

The depth to the maximum penetrometer value (depth to the hard pan) was negatively correlated with a range of measures determined from PL-FAME analysis of the soil, including fungi (r=-0.59), Gram-negative bacteria (r=-0.46), Gram-positive bacteria (r=-0.52), and the ratio of fungi to bacteria (r=-0.36).

3.1.6 Step forward multiple linear regression analysis

The weight of marketable fruit was taken as the response variable in the regression model, which best reflects plant health. The other measurements from the soil analysis and the grower survey were taken as explanatory variables reflecting soil health. The final regression model was taken at step 4 of the stepwise procedure, since at this step, the next variable to be selected was not significant at P=0.05. The model was:

$$Y = 4.88\ (\pm 6.93) + 2.53\ (\pm 0.75)\ X_1 + 7.88\ (\pm 2.43)\ X_2 + 0.0748\ (\pm 0.0301)\ X_3 - 1.12\ (\pm 0.60)\ X_4$$

(Unadjusted $100R^2$ = 55.7)

where Y = Weight of marketable fruit (t/ha)
X_1 = Total number of passes with an implement prior to cropping (0-∞)
X_2 = Grower rating of surface crusting of the site (0-3)
X_3 = Rate of N applied (kg/ha)
X_4 = Number of fumigations in the past 5 years (0-∞).

The number of passes with an implement prior to cropping, the grower rating of surface crusting of the soil, and the rate of applied N were explanatory variables positively correlated with the weight of marketable fruit, whereas the number of fumigations in the past 5 years was the explanatory variable negatively correlated with this yield parameter.

3.1.7 'Best subset regression screening' – confirmation of the stepwise procedure

As an alternative regression modelling approach to confirm (or otherwise) the results of the stepwise procedure, a 'best subset regression screening' procedure was conducted. As required by this procedure, only the variables considered most relevant to the weight of marketable fruit (plant health) were selected. The output from the 'best subset regression screening' showed the best 3 subset regressions for each subset size from 0 to 10 X variables (p=1 to 12) and the single regression with all 11 X variables fitted (p=12) (**Table 3.7**).

The 'best' subset size, which is where Cp approximately equals p (p and Cp are the first 2 columns in **Table 3.7**), is at approximately p=7; i.e. for 6 X variables. For p=7, there was not much difference between the top 3 regressions - all with an unadjusted $100R^2$ value of approximately 64%, and each of these containing the 4 X variables A, B, C, K (N applied, total number of passes with an implement, surface crusting, number of weed species). It can be concluded that these 4 common X variables are the main driving variables for the weight of marketable fruit, from the set of 11 X variables examined in the screening.

Table 3.7 - Best subset regression models for the dependent (Y) variable weight of marketable fruit

p	Cp	**Adjusted R^2**	**Unadjusted R^2**	Residual SS	Model variables
1	35.1	0	0	2245.610	Intercept only
2	22.3	0.2060	0.2333	1721.630	B
2	23.8	0.1813	0.2096	1775.040	A
2	28.2	0.1093	0.1400	1931.180	H
3	14.5	0.3449	0.3901	1369.570	B C
3	16	0.3183	0.3653	1425.250	A B
3	19.6	0.2579	0.3091	1551.550	A H
4	9.8	0.4377	0.4958	1132.130	A B C
4	12.8	0.3853	0.4489	1237.580	B C E
4	14.8	0.3492	0.4165	1310.290	B C D
5	7.9	0.4874	0.5581	992.376	A B C E
5	8.7	0.4718	0.5447	1022.460	A B C K
5	8.9	0.4691	0.5423	1027.820	A B C D
6	7.3	0.5161	0.5995	899.358	A B C E K
6	7.3	0.5158	0.5993	899.919	A B C H K
6	8.4	0.4944	0.5816	939.617	A B C D E
7	6.8	0.5446	0.6389	811.001	A B C H I K
7	6.9	0.5424	0.6371	814.910	A B C E H K
7	7.3	0.5340	0.6304	829.955	A B C E F K
8	6.6	0.5701	0.6739	732.317	A B C E F H K
8	7.4	0.5534	0.6612	760.875	A B C F H I K
8	7.7	0.5457	0.6554	773.892	A B C E H I K
9	7.4	0.5758	0.6928	689.878	A B C D E F H K
9	7.5	0.5721	0.6902	695.800	A B C E F H I K
9	8.5	0.5510	0.6748	730.194	A B C E F H J K
10	8.6	0.5714	0.7044	663.844	A B C D E F H J K
10	8.9	0.5648	0.6999	673.955	A B C D E F H I K
10	9.2	0.5574	0.6947	685.521	A B C E F H I J K
11	10	0.5636	0.7141	642.065	A B C D E F H I J K
11	10.6	0.5497	0.7050	662.517	A B C D E F G H J K
11	10.9	0.5420	0.6999	673.818	A B C D E F G H I K
12	12	0.5401	0.7145	641.042	A B C D E F G H I J K

The unforced independent (X) variables included (A) nitrogen application (B) total number of passes with an implement, (C) surface crusting, (D) weed pressure, (E) number of fumigations in the previous 5 years, (F) total number of parasitic nematodes, (G) fluorescine diacetate (FDA), (H) pH at 45-60 cm, (I) electrical conductivity at 45-60 cm, (J) gram-negative bacteria, and (K) number of weed species. The number of cases (sites) included was 30 out of a possible 36, since cases with missing data were not included in the analysis. The 3 'best' models from each subset size are listed.

3.1.8 Comparison of reference sites with crop sites

Table 3.8 - Amounts (µg/ g soil) of PL-FAMEs used as biomarkers for microbial functional groups and labile carbon in soil sampled from each reference site and its corresponding crop site at Bowen/Gumlu

Microbial functional group	Q1	Q1-1	Q4	Q4-1	Q9	Q9-1	Q11	Q11-1
Total bacteria	1.11	2.97	1.61	1.51	2.36	2.26	1.07	2.79
Gram +ve bacteria	0.88	2.13	1.10	1.06	1.67	1.59	0.76	1.90
Gram –ve bacteria	0.23	0.84	0.51	0.45	0.69	0.67	0.31	0.89
Fungi	0.06	0.27	0.11	0.19	0.19	0.45	0.08	0.39
VAM	0.12	0.28	0.14	0.14	0.19	0.21	0.12	0.36
Fungi : Bacteria	0.05	0.09	0.07	0.12	0.08	0.20	0.07	0.14
Total PL-FAMEs	3.80	10.30	5.20	4.80	7.40	8.50	3.20	10.60
C_1	0.78	1.94	0.63	2.45	1.16	0.71	0.79	1.90

The reference sites have the descriptor '-1' at their end for ease of identification.

The composition of the soil microbial community determined by PL-FAME analysis revealed that, in general, the reference sites tended to have higher levels of fungi and total PL-FAMEs than the corresponding crop sites (**Tables 3.8 & 3.9**). The level of C_1 followed a similar trend. With the exception of Q4-1 or Q9-1, levels of bacteria also tended to be higher in the reference sites than in the crop sites.

Table 3.9 - Amounts (µg/ g soil) of PL-FAMEs used as biomarkers for microbial functional groups and labile carbon in soil sampled from each reference site and its corresponding crop site at Bundaberg

Microbial functional group	Q14	Q14-1	Q17	Q17-1	Q24	Q24-1	Q31	Q31-1
Total bacteria	0.94	1.87	1.31	1.74	1.37	2.80	0.40	2.07
Gram +ve bacteria	0.54	0.95	0.84	0.91	0.95	1.76	0.25	1.36
Gram –ve bacteria	0.39	0.91	0.46	0.83	0.42	1.04	0.16	0.71
Fungi	0.03	0.25	0.03	0.30	0.02	0.26	0.01	0.08
VAM	0.08	0.13	0.09	0.09	0.04	0.25	0.01	0.15
Fungi : Bacteria	0.03	0.13	0.02	0.14	0.01	0.09	0.02	0.04
Total PL-FAMEs	3.29	7.13	4.15	6.52	3.79	9.95	1.25	6.62
C_1	0.86	1.56	1.16	0.63	0.94	1.35	0.66	2.63

The reference sites have the descriptor '-1' at their end for ease of identification.

3.2 Discussion

3.2.1 Capsicum yield

For the sites surveyed and the limited range of production systems investigated, bacterial-feeding nematodes, C_1, and mycorrhizae were considered to be useful measures of soil health and biological activity. These parameters were correlated with the greatest number of the other parameters deemed to be representative of a healthy soil. Therefore, a useful measure of soil health was made by each of the 3 laboratories collaborating in the project (viz. Biological Crop Protection, DNR, CSIRO, respectively), which indicates that several useful measures of soil health are possible.

In stark contrast, however, none of the soil health indicators was correlated with the fruit yield data. Indeed, the average weight of an individual marketable fruit was negatively correlated with fungi and the $\log_{10}$ of the number of colony forming units of fluorescent pseudomonads. The weight of marketable fruit per ha is considered to be an excellent measure of the health of a crop, since a large yield of high quality fruit is a manifestation of foliage with maximal photosynthetic capacity and root systems capable of absorbing sufficient water and nutrients. Therefore, whereas bacterial-feeding nematodes, C_1, or mycorrhizae were useful measures of soil health, they provided little indication of overall crop health in this work.

Both the step forward multiple regression analysis and the 'best subset regression screening' procedure revealed N applied and total number of passes with a tillage implement were among the main driving variables for weight of marketable fruit. This finding is in contrast to the assumption that practices that contribute to a healthy soil lead to a healthy crop.

Coupled with the fact that crop health and soil health parameters were either not correlated, or were negatively correlated, the data tends to support the ***'biological desert philosophy'*** discussed by Dr Dan Chellemi during his seminar at the Second Australasian Soil-borne Diseases Symposium (Chellemi & Porter 2001). As stated by Dr Chellemi, "for intensively cultivated horticultural crops, soil health and plant health may often be inversely related – e.g. fumigation increases plant health at the expense of soil health".

Both the 'step forward multiple regression analysis' and the 'best subset regression screening' procedures showed that the more the grower rated their soil as being cloddy with big chunks, dusty and powdery, the lower was the weight of marketable capsicum fruit. The former statistical analysis also showed that the number of soil fumigations in the previous 5 years was negatively correlated with this yield parameter. A soil with poor structure can be a manifestation of low organic matter.

3.2.2 Soil carbon

Soil fumigation destroys microbes beneficial to soil structure, such as mycorrhizae, which entangle and enmesh soil particles with their hyphae to form macro-aggregate structures. The stable glue holding the hyphae to soil particles is glomalin, a glycoprotein deposited on the cell wall of the extraradical mycelium (Wright and Upadhyaya 1998). Therefore, these findings broadly support the hypothesis that labile C (particularly C_1) is the food source for a diverse microbial food web, and ultimately leads to a well-structured and healthy soil (the ***'labile C soil food web philosophy'***).

The fact that C_1 was correlated with at least nine biological parameters versus two for C_3, or just one for total C supports the hypothesis that labile C, measured in this project as the C_1 fraction, provides the primary source of C on which the soil food web ultimately depends. C_1 comprises organic compounds more easily oxidisable than those oxidised by C_3. C_3 compounds have been identified as polysaccharides and some phenolic compounds (Conteh et al. 1999). It can be inferred that C_1 comprises simple sugars and carboxylic acids.

The generally higher levels of fungi, bacteria and total PL-FAMEs in the reference sites than in the corresponding crop sites reflect the depleted microbial status of the crop sites. The fact that the amount of C_1 was generally much higher in the reference sites than in the crop sites supports the theory that labile C is a vital primary food source for the soil food web. These results also tell us that the way in which we are farming is detrimental to the health of our soils in the long term.

The data suggests that augmenting the C_1 fraction of the soil would improve soil structure and ultimately lead to diverse microbial populations. Addition of organic matter will achieve this objective. Practices such as green manure cropping, addition of plant materials such as filter press or composted garden waste, or the application of organic fertilisers such as animal manures would add labile C to the soil.

The negative correlation between weight of marketable fruit and the C:N ratio of the soil probably reflects an N draw-down effect by residual C in the soil leading to N deficiency in the crop. Therefore, organic materials of high C:N ratio need to be composted before incorporation into the soil, otherwise sufficient time should be allowed for their breakdown in the soil before planting the crop. Since growers in this survey did not use muriate fertilisers, Cl was only applied in certain instances. This practice of limited use of muriate fertilisers is recommended, since Cl is a harmful to soil biota.

The poorly developed root system of capsicums and the fact that the mean depth to the first maximum penetrometer value was 487 mm indicated that, in general, the depth of the hard pan was probably not a major impediment to the growth of roots in the soil. The negative relationship between the depth to the hard pan and fungi, Gram-negative bacteria, Gram-positive bacteria, and the ratio of fungi:bacteria determined by PL-FAME analysis may reflect a higher moisture content in soils with a shallow hard pan than in soils with a deep hard pan, or perhaps a concentration effect of the biota in the soil to the edaphic zone above the hard layer.

3.2.3 Management practices

Based on the cultivation, tillage, fallow, fumigation, nutrition, and crop rotation practices used, the survey results indicate that that an intensive cropping program was employed at most sites. In the 5 years preceding this study, the high average number of solanaceous crops grown (3.8) and fumigations used (2.3), and the low average numbers of fallows employed (0.8) or green manure crops grown (1.3) indicate a general disregard for sound crop management practices or addition of C to the soil.

The general absence of sudden wilt from the sites at sampling suggests that this root disease complex was not directly related to any one of the management practices that were documented. However, the fact that a soil fumigant was applied to greater than 50% of the crop sites surveyed may have masked any effect of soil management on soil health.

The positive relationship between the number of solanaceous crops and soil fumigations in the past 5 years indicated awareness by growers of the need to fumigate in the absence of sound crop rotation practices. The negative relationship between the number of solanaceous crops and various biological parameters in the soil may have been associated more with the frequency of fumigation than with the presence of actual solanaceous crops. It may be inferred that the poor relationship between the application of a soil fumigant prior to planting the capsicum crop and the biological indicators (compare **Tables 3.4 & 3.5**) reflect (1) low biological activity, (2) high buffering capacity which facilitates the rapid reestablishment of microflora, or (3) a lack of efficacy of the fumigant. The latter of these hypotheses supports the case of biodegradation of metham sodium by soil microflora, since this fumigant was applied at the majority of the fumigated sites (14 of 19). Enhanced degradation of metham sodium in Australia was reported by Warton & Matthiessen (2000).

The rates of applied nutrients were not excessive, based on the information provided by growers in the questionnaire. Relative to the other nutrients, the high quantity of K applied (average of 171 kg/ha) was consistent with the fact that this element is removed to the greatest extent by capsicum crops (Olsen et al.1993).

3.2.4 Nutrient management

The lack of cases in which the micronutrients Zn, Cu, Fe, B, Mo, and Mn were applied may reflect the fact that Zn, Cu, and Mn are present in commercially available fungicides, and Fe is usually abundant in water used from underground sources. However, the absence of B and Mo from the fertiliser strategy may reflect (1) an oversight by growers to include foliar sprays of micronutrients in their list of fertilisers, (2) a considered opinion that these elements are not important for optimal capsicum production, or (3) a disregard of the importance of these micronutrients for crop nutrition. Whereas overt signs of deficiency symptoms of B (necrotic terminal bud/deformed fruit) or Mo (pale, cup-shaped leaves curling upwards because of death at the margins) were not obvious in the capsicum crops grown at the sites we inspected, it is possible that these elements may still have been limiting to optimal fruit yield. A small application of these micronutrients may well increase yield, or at least provide a buffer against future deficiency symptoms. Experience has shown that the B level in the soils around the Bundaberg district is often below the desirable range of 2-5 mg $CaCl_2$ extractable B/kg soil reported as necessary for capsicum (Incitec 1989). Therefore, applications of this element on a regular basis are recommended for optimal yields.

Whereas deficiency symptoms were not observed on plants, evidence of a supra-optimal N supply was evident at some sites. For example, plants at Q28-29 were lush, dark green, and had lodged, which exposed the fruit to the sun and caused sunburn. The nitrate concentration of sap expressed from the petioles of plants grown at Q29 was 4,520 mg/L, which was high when compared with the critical sap nitrate concentration for plants of a similar age (1,500 mg NO_3/ L - Olsen and Lyons 1994). Petiole length is often a good indicator of N status, and the length for mature plants of most commercial cultivars is typically 5 cm. Petioles up to 14 cm in length were measured at Q29 (photos available upon request). According to the records obtained from the grower and a double check of fertilisers listed, a low total application of 91.6 kg N/ha was applied to the crops at each site. It is possible that the observed effect of supra-optimal N at Q28 and Q29 was the result of the application of methyl bromide prior to cropping. Methyl bromide may stimulate the uptake of N by the plant in two ways. Firstly, the fumigant may free up immobilised N from the proteins of biota in the soil. Secondly, roots growing in soil free of pathogens are healthy, and so, take up more nutrients than necrotic roots.

3.2.5 Irrigation

The average quantity of irrigation water applied to each crop (2.5 ML/ha) agreed closely with the reported 2-3 ML/ha estimated by Grattidge (1990). Although some growers used the services of a crop consultant for irrigation scheduling, the majority of growers did not use any form of irrigation scheduling at the sites we investigated.

3.2.6 Electrical conductivity

The influence of Na in the exchange complex on soil structure was evident from the results, since the grower rating of cloddiness (1=cloddy, 3=crumbly and granular) was correlated with the electrical conductivity (EC) of the soil at depths of both 0-15 and 45-60 cm. High concentrations of NaCl in the groundwater irrigation supplies of all 3 localities (Bowen/Gumlu, Bundaberg, Gatton) provide a source of Na.

3.2.7 Crop health

At the time of sampling each site, the crop was rated for a range of crop health parameters by the researchers conducting the survey. Whereas the crop appearance and health of the foliage were correlated with the average weight of an individual marketable fruit, neither rating was correlated with the total weight of marketable fruit harvested from the site. This result could indicate (1) that the health of the foliage and the plant tops were not useful indicators of yield, or (2) that a cursory examination of plants at one snapshot in time is not sufficient to predict final yield, since unforeseen environmental conditions may occur at a later time which have a significant impact on yield potential.

3.3 Conclusion & Recommendations

What were the best indicators of soil health? Bacterial-feeding nematodes, C_1, and mycorrhizae were considered to be useful measures of soil health and biological activity. These parameters measured by laboratories at Biological Crop Protection, DNR, CSIRO laboratories, respectively, indicated that several useful measures of soil health are possible.

How well did crop health correlate with soil health? Not well. In fact, the management strategies that ultimately lead to poor soil health in the long term were actually those measures that correlated best with the health of the crop (viz. marketable yield). The data supported both the 'biological desert philosophy' (that soil should be a sterile medium to prop up the plant) and the 'labile C soil food web philosophy' that labile C (particularly C_1) is the food source for a diverse microbial food web, and ultimately leads to a well-structured and healthy soil.

How well were farmers treating their soil? Not all that well. In the 5 years preceding the study, the high number of solanaceous crops grown (3.8) and fumigations used (2.3), and the low number of fallows employed (0.8) or green manure crops grown (1.3) indicated a general disregard for sound crop management practices or addition of C to the soil. A soil fumigant was applied to greater than 50% of the crop sites surveyed.

What did the reference sites tell us? The generally higher levels of fungi, bacteria and total PL-FAMEs in the reference sites than in the corresponding crop sites reflect the depleted microbial status of the crop sites. The fact that the amount of C_1 was much higher in general in the reference sites than in the crop sites supports the theory that labile C is a vital primary food source for the soil food web. These results also tell us that the way in which we are farming is detrimental to the health of our soils in the long term.

What can be done to improve soil health? The data suggests that augmenting the C_1 fraction of the soil would improve soil structure and ultimately lead to diverse microbial populations. Addition of organic matter will achieve this objective. Practices such as green manure cropping, addition of plant materials such as filter press or composted garden waste, or the application of organic fertilisers such as animal manures would add labile C to the soil. Organic materials of high C: N ratio need to be composted before application, otherwise sufficient time should be allowed for their breakdown in the soil before planting the crop. Since growers in this survey did not use muriate fertilisers, Cl was only applied in certain instances. This practice of limited use of muriate fertilisers is recommended, since Cl is harmful to soil biota.

Was there a hard pan and did it cause a problem? No. The hard pan was deep (487 mm) and would not have been a factor in soil health or crop health.

Was nutrient management an issue? The rates of applied nutrients were not excessive, based on the information provided by growers in the questionnaire. No obvious signs of nutrient deficiency were encountered. A small application of B and Mo is recommended for each future crop to provide a buffer against future deficiency symptoms. Excessive amounts of N in the crop were detected in only 2 of the 36 crop sites surveyed.

4. Carrot soils - Tasmania, NSW & Victoria

4.1 Results

4.1.1 Profiles of surveyed cropped sites profiles

Some of the information on the surveyed carrot sites, such as locations, soil types, cropping history, and soil management is given in **Tables 4.1** and **4.2**.

In Tasmania, 71% of the carrot sites surveyed have been intensively used for vegetable production, while 26% have intermediate use in between pasture or other non-vegetable crops, and only one site (3%) was used in between long term pasture (**Table 4.1**). In Tasmania, the practice of incorporating breaks in between vegetable crops by fallowing ground or sowing with green manure crops was recorded in 31% and 20% of the sites, respectively, in the previous 5-year period (**Table 4.2**). These percentages are believed to be representative of the land use on the north-west coast of Tasmania.

In Victoria, all the carrot sites surveyed were from areas that had been used intensively for vegetable production, while in NSW, 50 % of the sites were from intensive vegetable production areas. As only a few sites were surveyed in NSW and Victoria, with two to three sites from the same grower, the practices noted in **Tables 4.1** and **4.2** may not be representative of those states.

Of the 35 carrot sites surveyed in Tasmania, soil fumigant (sodium metham) was applied only at one site, while no soil fumigant was used at any of the carrot sites surveyed in NSW (6 sites) or Victoria (3 sites).

The total number of passes with rotary cultivation equipment used in pre-plant soil preparation, which includes passes with a rotary hoe or power harrow are detailed in **Table 4.2**. Other equipment used in soil cultivation included ploughs, agrow plows and discs.

Increased inputs into farming systems, e.g. irrigation, fertilisers, herbicides, fungicides and insecticides, was recorded over the previous 5-year period by many growers (**Table 4.2**). Tasmanian growers observed that water infiltrates slowly, with some run-off or ponding after heavy rain in 50% of the sites.

Table 4.1 - The location, cropping history, and types of crop rotations used prior to carrots in the surveyed sites in Tasmania

State	Site	Location	Soil type	History of vegetable production on site (Q2)*	Previous crops sown in last 3 years (Q1)*		
					Year 1	Year 2	Year 3
Tas	T01	Forth	Ferrosol	Intensive	Poppy / Tamar grass	Tamar grass / Pyrethrum	Pyrethrum
	T02	Kindred	"	Intensive	Poppy	-	-
	T03	Kindred	"	Intensive	Potato	Poppy	Pasture
	T04	Forth	"	Intensive	Tamar grass / Potato	Onion	Grass
	T05	Sassafras	"	Intensive	Broccoli / Pea	Poppy	Potato
	T06	Moriarty	"	Intermediate	Potato	Pasture	Pasture
	T07	Sassafras	"	Intermediate	Pea	Onion	Poppy
	T08	Latrobe	"	Intensive	Oat	Fallow / Broccoli / Pea	Poppy / Fallow
	T09	Wesley vale	"	Intensive	Broccoli / Cauliflower	Pea	Poppy
	T10	Wesley Vale	"	Intensive	Onion	Cauliflower / Broccoli	Poppy
	T11	Forth	"	Intensive	Carrots / Wheat	Grass / Poppy	Onion
	T12	Kindred	"	Intensive	Carrots	Potato	Poppy
	T13	Kindred	"	Intensive	Wheat	Potato	Broccoli
	T14	Forth	"	Intensive	Pyrethrum	Pyrethrum	Pyrethrum
	T15	Sunnyside	"	Intermediate	Poppy / Grass	Onion	Grass
	T16	Sprent	"	Intermediate	-	Onion	Barley
	T21	Cuprona	"	Intermediate	Annual Grass / Potato	Poppy	Pasture
	T22	Forth	"	Intensive	Poppy	Pea / Bean	Carrots
	T23	Thirlstane	"	Between pasture	Onion	Poppy	Pasture
	T24	Thirlstane	"	Intensive	Poppy	Bean	Pasture
	T25	Cuprona	"	Intermediate	Broccoli	Poppy	Pea
	T26	Forth	"	Intensive	Brussel sprout / Pea	Onion	Poppy
	T27	Don	"	Intensive	Pea / Bean	Pyrethrum	Pyrethrum
	T28	Kindred	"	Intensive	Poppy	Onion	Pumpkins
	T29	Sassafras	"	Intensive	Poppy	Potato	Pea
	T30	Forth	"	Intensive	Onion	Poppy	Potato
	T31	Sassafras	"	Intermediate	Beans	Pea	Broccoli / potato
	T32	Forth	"	Intensive	Potato	Poppy	Onion
	T33	Don	"	Intermediate	Potato	Poppy	Pasture
	T34	Latrobe	"	Intensive	Pea	Poppy	Pea / Oat
	T35	Don	"	Intermediate	Poppy	Pea	Potato
	T37	Forth	"	Intermediate	Oat	Carrots	Poppy
	T38	Forth	"	Intensive	Fallow / Broccoli / Pea	Poppy	Pea / Broccoli
	T39	Forth	"	Intensive	Barley	Potato	Pea
	T40	Kindred	"	Intensive	Poppy	-	-
Vic	V2	Yarrawonga	Sandmount sand over Cobram loam	Intensive	Cabbage / Spinach	Potato / Carrot	Potato / Pasture
	V3	Yarrawonga		Intensive	Cabbage / Spinach	Potato / Carrot	Potato / Pasture
	V4	Yarrawonga		Intensive	Cabbage / Spinach	Pumpkin / Carrot	-
NSW	N1	Beneramba	Vertosol	Intermediate	Onion	Barley	Carrot
	N2	Beneramba	"	Intermediate	Wheat	Carrot	Onion
	N3	Beneramba	"	Intermediate	Wheat	Onion	Wheat
	N5	Cookathama	Red Kandosol	Intensive	Onion	Carrot	Fallow
	N6	Cookathama	"	Intensive	Onion	Carrot	Fallow
	N7	Cookathama	"	Intensive	Carrot	Onion	Carrot

* Q = Question number in survey form

Table 4.2 - Soil management and preparation conducted by the grower at each surveyed carrot site, and observations on the farm input and water infiltration rate

Site	No. times site fallowed in past 5 years (Q1)*	No. times a green manure crop grown in past 5 years (Q1)*	Total no. passes with cultivation equipment (Q13)*	Total no. passes with rotary hoe/power harrows (Q13)*	Increased Usage over past 5 years (Q6)	Water infiltration (Q20)*
Tas						
T01	0	0	2	1	Irrigation	Slow, some ponding
T02	0	0	4	2	N/a	Rapid, no ponding
T03	1	0	3	1	Irrigation	Slow, some ponding
T04	0	0	3	2	N/a	Slow, some ponding
T05	2	0	5	2	Fertiliser	Slow, some ponding
T06	4	0	4	1	Irrigation	Slow, some ponding
T07	0	0	3	1	N/al	Slow, some ponding
T08	3	0	N/a	N/a	Irrigation	Rapid, no ponding
T09	0	0	3	1	Irrigation	Slow, some ponding
T10	0	0	3	1	Irrigation	Rapid, no ponding
T11	0	0	3	1	N/a	Rapid, no ponding
T12	0	0	4	1	Irrigation / Herbicides / Fungicides	Rapid, no ponding
T13	0	0	4	3	Irrigation / Fungicides / Insecticides	Slow, some ponding
T14	0	0	4	1	Irrigation	Rapid, no ponding
T15	0	0	3	1	Irrigation / Fungicides	Slow, some ponding
T16	0	0	4	1	Irrigation / Fertiliser / Herbicide	Rapid, no ponding
T21	3	3	4	2	Irrigation	Rapid, no ponding
T22	0	1	7	3	Irrigation / Fertiliser / Herbicides / Fungicides / Nematicides	Slow, some ponding
T23	4	4	5	3	Irrigation	N/a
T24	2	2	5	3	Irrigation / Fungicides / Insecticides	Rapid, no ponding
T25	0	1	4	2	Irrigation / Fungicides / Herbicides	Rapid, no ponding
T26	0	0	4	2	Irrigation / Herbicides / Fungicides / Insecticides	Rapid, no ponding
T27	0	0	N/a	N/a	Irrigation / Herbicides / Fungicides / Insecticides	Slow, some ponding
T28	0	0	4	1	Irrigation	Slow, some ponding
T29	2	2	6	1	Fertiliser	Slow, some ponding
T30	0	0	3	1	Irrigation / Herbicides / Fungicides / Insecticides	Slow, some ponding
T31	0	0	3	1	Irrigation / Herbicides	Rapid, no ponding
T32	0	0	6	3	Fertiliser / Fungicides	Rapid, no ponding
T33	1	0	4	2	Irrigation	Slow, some ponding
T34	2	0	4	2	N/a	Rapid, no ponding
T35	0	0	3	1	Irrigation / Fungicides	Rapid, no ponding
T37	0	0	3	1	Irrigation	Slow, some ponding
T38	3	2	4	2	Irrigation / Fertiliser	Rapid, no ponding
T39	0	0	4	1	Irrigation	Slow, some ponding
T40	0	0	2	0	Irrigation / Fertiliser	Rapid, no ponding
Vic						
V2	3	0	5	1	Same	Rapid, no ponding
V3	0	0	5	1	Same	Rapid, no ponding
V4	0	0	5	1	Same	Rapid, no ponding
NSW						
N1	0	0	4	1	Herbicides	Rapid, no ponding
N2	1	0	4	3	Herbicides	Rapid, no ponding
N3	2	0	6	1	Herbicides	Rapid, no ponding
N5	2	0	6	3	Fertilisers	Slow, some ponding
N6	2	0	5	0	Fertilisers / Herbicides	Slow, some ponding
N7	1	0	5	2	Irrigation / Fertilisers / Herbicides	Slow, some ponding

* Q = Question number in survey form

4.1.2 Effects of soil factors on carrot yield and quality

Except for two crops that were produced for processing into frozen vegetables, all carrot crops surveyed in Tasmania were produced for the fresh market. Therefore, crops were assessed according to the high standard used by the fresh market industry in Tasmania. In NSW, carrots were produced for juicing.

Carrots produced for fresh market are subjected to a high quality standard, where carrots are sorted according to colour, size and appearance (**Photograph 3**). Growers are paid according to the carrot weight and packout rate (i.e. the percentage of marketable carrots). The yield assessed in this study was based on the total number of marketable carrots (all adjusted to 3 double row carrots/m^2 bed) instead of carrot weights because carrots for the survey were harvested one to three weeks before commercial harvest. The exact timing of commercial harvest was difficult to predict, as harvesting is dependent on a combination of weather, availability of harvester, washing and sorting capacity, and market demand.

Photograph 3: Quality of carrot samples from a crop site in Tasmania. Only the first four (top left) are deemed to be acceptable for fresh market. Misshapen, forked, diseased and undersized carrots are rejected

The matrix of all possible pair-wise correlation coefficients was conducted on data from the 35 carrot sites on Ferrosol soils in Tasmania. Soil factors that are significantly correlated to carrot yield and quality in the pair-wise correlation are listed in **Table 4.3**. These factors are considered of interest and warrant further investigation in a multiple step-wise regression analysis to identify dominant factors influencing carrot yield and quality.

The soil types from NSW and Victoria were different to those in Tasmania, and hence were not included in the correlation analysis and linear multiple regression analysis. The number of sites surveyed in NSW (8 sites with two soil types) and Victoria (4 sites) were also too few for the comparative analysis.

Table 4.3 - Soil factors that are significantly correlated to carrot yield and quality in the matrix of all possible pair-wise correlation on all information collected from the carrot sites in Tasmania

Marketable carrots	% Packout	% Diseased	% Misshapen	% Non-diseased
pen. resistance at 300 mm (-)	% Diseased (-)	depth of max. pen (-)	weeds no.	Misshapen
deep cult (-)	% Misshapen (-)	pen. resistance at 150 mm	yield ch (-)	Smell (-)
no. rotary passes	Erosion	Erosion (-)	BFN (-)	Gr rate (-)
cloddiness (-)	Total C	% Packout (-)	% Packout (-)	weeds no.
infiltration (-)	Total N			BFN (-)
% FFN (-)	C3			Omniv
% BFN				Actino
FFN:BFN(-)				C1/Total C
				Packout (-)

Correlation coefficient values greater than 0.325 in the matrix of all possible pair-wise simple correlation coefficients of 35 carrot sites were significant at *P*=0.05.

Carrot yield

The multiple linear regression model that best describes the carrot yield is:

$$\mathbf{Y = 51.99 - 0.012X_1 + 7.78X_2 + 0.41X_3}$$, where

Y	=	Yield (Total number of marketable carrot per m^2)
X_1	=	Soil penetration resistance over 150-300mm
X_2	=	Total number of rotary passes with rotary hoe or power harrow
X_3	=	% Bacteria feeding nematode (% BFN)

The main factors that significantly affected carrot yield ($P < 0.01$) were the soil penetration resistance, the total number of cultivation passes with a rotary hoe or a power harrow, and % BFN. The R-Squared statistic indicates that the fitted model explains 35.9% of the variability in carrot yield. According to the model, the yield of carrot increased with an increase in % BFN and the total number of rotary passes, but decreased with an increase in the soil penetration resistance at 300 mm depth.

The total number of rotary passes and soil penetration resistance over 150-300 mm was inter-related. The matrix correlation analysis showed that soil penetration resistance over 150-300 mm was correlated to soil cloddiness and soil penetration resistance over 0-150 mm depth. These suggest that good soil preparation is vital in carrot production and that the yield of carrot is affected by soil physical structure.

The relationship of % BFN with yield appeared to be coincidental. The percentage of BFN was usually higher in cropped soils compared to non-cropped soils. Populations of saprophytic fungi are reduced due to soil disturbances by cultivation, and high nitrogen inputs. Therefore, intensively cropped soil tended to have a bacterial-dominant soil food-web. Percentage BFN was negatively correlated with % FFN (fungal feeding nematodes), and % Omniv (omnivorous nematodes).

Carrot quality

The multiple linear regression model that best describes carrot quality, as determined by the carrot packout rate is:

$$\mathbf{Y = 76.40 - 0.67X_1 - 0.91X_2 + 0.25X_3}$$ **, where**

Y	=	% Packout (percentage of carrots that are marketable)
X_1	=	% Misshapen carrots
X_2	=	% Diseased carrots
X_3	=	Total carbon in topsoil (0 to 150 mm depth)

The main factors that significantly affected carrot quality ($P < 0.01$) were % misshapen carrots, % diseased carrots, and total carbon in topsoil, where the R-Squared statistic indicates that the model as fitted explains 68.1% of the variability in % packout.

Percentage packout, % diseased carrots and % misshapen carrots, are inter-related quality assessments values (**Photograph 3**). This indicated that diseased and misshapen carrots were the main causes of reduced carrot packout or quality. In contrast, total soil carbon had a positive relationship to carrot packout, i.e. increased soil carbon increased carrot packout. Total soil carbon is a quantitative value determined by soil chemical analysis, and is an important measure of soil quality or soil health.

Diseased carrots

The appearance of fresh market carrots is critical, and therefore, any obvious rot or lesions due to root diseases are unacceptable. Most of the diseased carrots had superficial lesions that developed at the crown (**Photograph 4**). The multiple-linear regression model that best describes the influence of soil factors on diseased carrots is:

$$Y = 10.98 + 0.018\,X_1 - 5.68X_2 \text{ , where}$$

Y = % Diseased carrots
X_1 = Soil penetration resistance over 0-150 mm
X_2 = Soil erosion (growers' perception of soil erosion at sampling site, where 1=severe erosion, 2=moderate erosion, 3=topsoil resists erosion)

The main factors that significantly influenced % diseased carrots ($P < 0.01$) were the soil penetration resistance over 0-150 mm and soil erosion, where the R-Squared statistic indicates that the model as fitted explains 42.2% of the variability in % diseased carrots. Soil penetration resistance is a quantitative measurement, whereas soil erosion is a qualitative rating based on growers' perceptions, as obtained from the survey questionnaire. These two values indicated that structural properties of topsoil have a direct influence on disease development in carrots, because % diseased carrots increased with an increase in topsoil penetration resistance, and an increase in topsoil erosion.

Photograph 4: Crown rot on carrots, the most common cause of diseased carrots

Photograph 6: Fine tap roots (far right) in the early growth stages are susceptible to impeded vertical growth

Photograph 5: Misshapen and forked carrots from Site T11

Misshapen carrots

The shape of carrots produced for the fresh market is extremely important. Any carrots that are obviously misshapen (**Photograph 5**) are unacceptable for the fresh market, and are often discarded as stockfeed or downgraded for use in processing (juicing or diced vegetables). Almost all misshapen carrots had the disorder at depths of between 40 to 85 mm. Often, the soil depth where the disorder occurred on the carrot roots tended to be similar for carrots at the same site (**Photograph 5**). This shows that the fine tap roots of carrot seedlings are most susceptible to impeded vertical growth (**Photograph 6**).

The multiple-linear regression model that best describes the influence of soil factors on misshapen carrots is:

$$\mathbf{Y = 8.56 + 1.36X_1 - 1.75^* X_2}$$

Y	=	% Misshapen carrots (bending of carrots, excludes forked carrots)
X_1	=	Total number of weed types
X_2	=	Total number of rotary passes with rotary hoe or power harrow

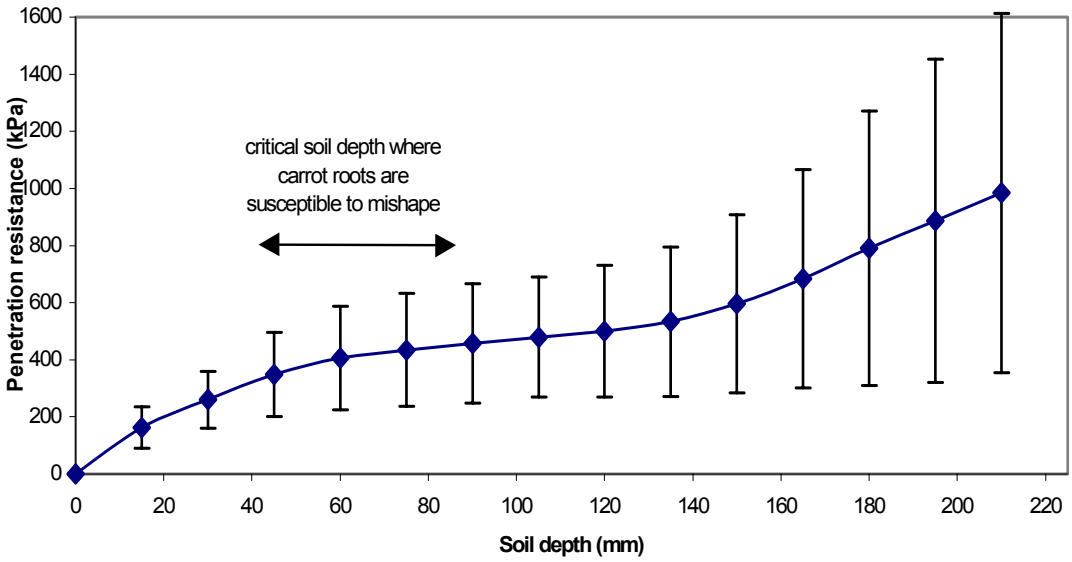
The main factors that significantly influenced % misshapen carrots ($P < 0.01$) are the total number of rotary passes with a rotary hoe or power harrow, and the total number of weed types. The R-Squared statistic indicates that the model as fitted explains 26.4% of the variability in % misshapen carrots. Percentage misshapen carrots was positively correlated to the total number of weed types, but negatively correlated to the total number of rotary passes. The total number of weed types present could be an indirect indicator of poor soil management and preparation, as well as poor crop management.

The significant effects of the number of rotary passes suggest that the soil preparation is also important in affecting the physical shape of the root growth, where a fine soil tilth could help reduce misshapen carrots. However, it is interesting to note that the topsoil penetration resistance over 0-150 mm is not correlated to % misshapen carrots.

There was a wide range of penetration resistance values measured, as shown by the maximum and minimum standard deviation of the surveyed sites (**Figure 1**). However, the average soil penetration resistance values over 0-150 mm are still within a range that is generally considered to have no effect on seedling root growth. In general, a soil with a penetration resistance of 1000 kPa or more is believed to pose a serious impediment to seedling root growth of plants (Cass 1999).

This suggests that instead of general soil compaction, the presence of small soil clods beneath the soil surface is more likely to cause impeded root growth. Under dry or low soil moisture, many of these small clods become very hard, making it difficult for the fine tap root of carrots to grow through it. Some cultivation equipment, such as the rotary hoe, have also been noted for their tendency to re-sort small soil clods and concentrate them in the zone where impeded root growth occurs.

Figure 4.1 - Average penetration resistance and standard deviation of measurements taken from 35 Tasmanian carrot sites from 15 to 215 mm soil depth



Nutrient management

Typically, fertiliser consisting of the major nutrient elements (N, P, K) is applied just before or at sowing of carrot seeds. Unlike capsicum crops in Queensland, carrots are deep rooted and have relatively low nutrient input. The average nutrient rates applied to carrot crops in Tasmania were 74, 91 and 86 kg/ha of N, P and K, respectively. Fertiliser input was found to have no significant impact on carrot production.

4.1.3 Soil physical properties

Soil penetration resistance

The soil penetration resistance is a measure of soil compaction, and following cultivation; the ground will become more compacted over time as the soil settles. Listed in **Table 4.4** are the soil depths where the maximum penetration resistance occurred, and average soil penetration resistance measured over 0-150 mm and 150-300 mm for each site.

The depth to the first maximum penetrometer value was taken as a measure to the depth of any hard pan. The values obtained in Tasmania and NSW all exceeded 500 mm, which is considered to be beyond the depth that would influence carrot growth. These values suggest that depth of the hard pan is unlikely to be a limiting factor for carrot root growth. Typically, the average length for carrots destined for fresh market ranged from 160 to 210 mm. At 150-300 mm depth, some sites have readings that are in excess of 1000 kPa, which therefore, may be limiting to early root growth.

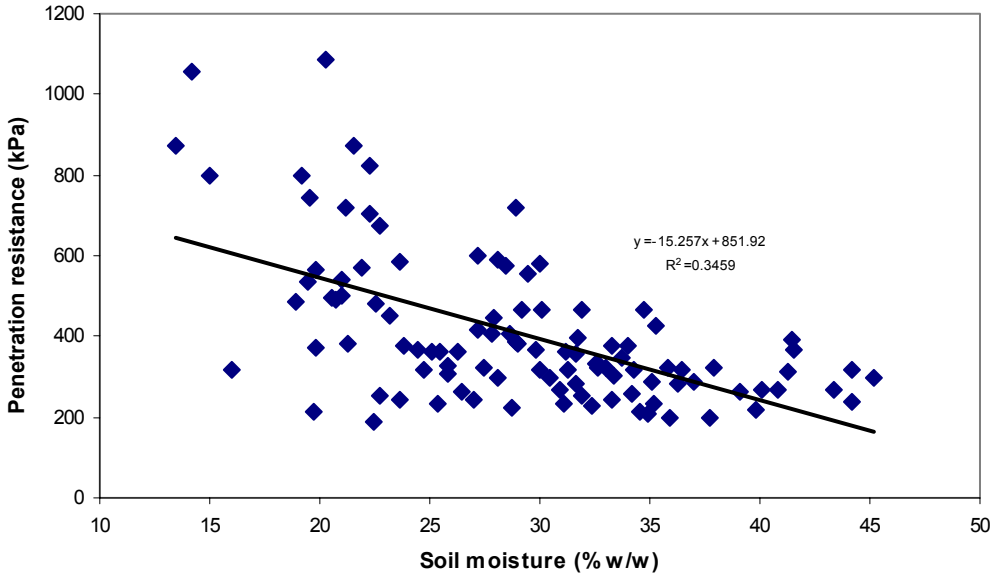
Table 4.4 - The soil penetration resistance measurements taken at each carrot crop site in Tasmania*

Site	Soil depth (mm), where the maximum penetration resistance was recorded (mm)	Average soil penetration resistance (kPa), measured over the soil depth of 0-150 mm	150-300 mm**
T25	525	240	448
T15	540	297	523
T26	555	226	524
T14	600	293	547
T11	600	298	563
T40	540	227	585
T23	570	246	588
T27	585	395	626
T21	585	268	651
T22	510	348	653
T9	600	389	718
T24	495	436	758
T32	405	374	777
T30	510	272	792
T39	570	312	799
T29	585	283	866
T4	510	267	884
T35	555	310	957
T28	525	215	991
T33	585	358	999
T37	525	404	1158
T34	510	616	1159
T6	465	359	1187
T10	450	533	1210
T8	570	564	1445
T16	600	403	1445
T5	465	550	1497
T13	480	710	1561
T1	465	451	1586
T38	390	441	1934
T31	360	828	1944
T12	510	559	1944
T2	360	579	1986
T3	405	475	1997
T7	435	747	2271

* Measurements conducted by Bill Cotching, Department of Primary Industry, Water & Environment, Tas,
** Note that values from all the sites were sorted according to soil penetration resistance values over 150-300 mm in an ascending order

Penetration resistance is dependent on moisture content. Therefore, soil moisture content at the time of penetrometer measurements was determined on samples from four depths (0-150 mm, 150-300 mm, 300-450 mm, 450-600 mm). At 0-150 mm and 150-300 mm depth, there was a negative correlation between moisture content and penetration resistance (**Figure 4.2**). In deeper soil, at 300-450 mm and 450-600 mm depth, there was little or no correlation between moisture content and penetration resistance.

Figure 4.2 - The relationship between penetration resistance and soil moisture content at 0-150 mm on Tasmanian soils sampled in 2000



Penetration resistance exceeded 2000 kPa at 300-600 mm depth at many sites. Due to the absence of a relationship between moisture content and penetration resistance, we conclude that differences in penetration resistance are due to site or management factors.

There was a greater range of penetration resistance at 150-300 mm depth than 0-150 mm in Tasmania, probably due to greater impacts of compaction and less effects of tillage.

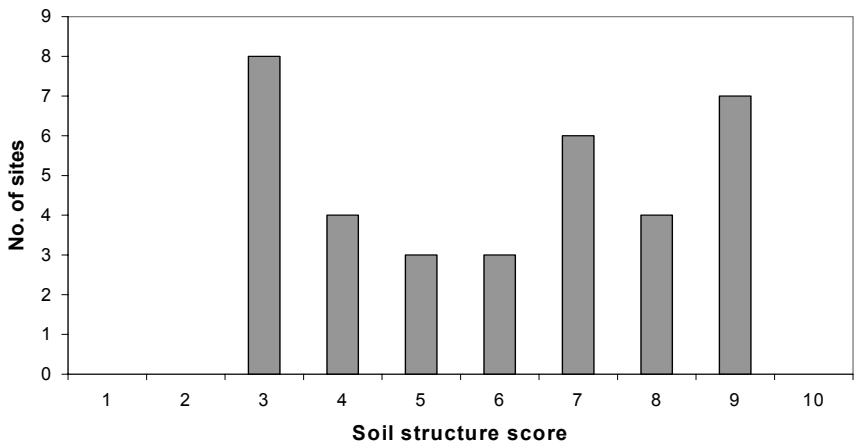
Soil structure score

Figure 4.3 shows the distribution of soil structure scores. The scores, ranging from 1 to 10, were based on visual assessments according to soil cloddiness as shown in the soil structure scorecard (**Appendix 4**).

Reference sites in Tasmania had visibly better structure than carrot sites, and sites in 2001 were visibly better on average than those in 2000.

In Tasmania, the soil structure score has a positive correlation to the total number of fallow period in the previous 5 years, the total number of green manure crops sown in the previous 5 years, omnivorous nematodes and total fungi (the latter two values determined by Biological Crop Protection's laboratory).

Figure 4.3 - The frequency of sites with a soil structure score ranging from 1 to 10



4.1.4 Soil chemical analysis

C & N levels

The total carbon (Total C), total nitrogen (Total N), oxidisable or labile carbon fractions (C1 and C3), pH and electrical conductivity (EC) are listed in **Tables 4.5 & 4.6**. The carbon fraction 1 (C1), which was extracted with 33mM KMnO4, is generally considered the most accessible and hence the most useful labile or organic carbon. Carbon fraction 3, extracted with 333mM KMnO4, is the least accessible organic carbon.

Table 4.5 - Analytical tests of Tasmanian soils for carbon, nitrogen, pH and electrical conductivity*

	Depth 0-15 cm						MBC	Depth 0-15 cm		Depth 45-60 cm	
Site	Total C ** (g.kg)	Total N (g/kg)	C:N	C1 (g/kg)	C3 (g/kg)	C1/ Tot C	(mg/kg)	pHw	EC (mS/m)	pHw	EC (mS/m)
Tas											
T24	24.5	1.3	18.8	1.8	4.4	7.2	79.8	6.5	16.5	6.6	10.0
T07	30.5	2.0	15.0	1.8	4.5	6.0	75.8	6.1	11.5	6.1	5.6
T04	32.3	3.7	8.7	2.3	4.7	7.2	75.8	7.0	10.6	6.3	8.6
T23	33.3	2.3	14.5	2.3	3.9	6.8	139.6	6.3	13.2	6.3	7.6
T30	34.2	2.3	14.7	2.5	5.9	7.4	99.6	6.3	8.5	6.3	8.8
T10	34.7	2.5	13.9	2.6	4.2	7.4	99.2	7.4	16.5	6.5	19.7
T03	35.1	3.1	11.3	2.6	3.9	7.3	56.8	6.9	12.5	6.3	6.5
T32	36.7	2.6	14.3	2.6	11.2	6.9	103.6	7.0	5.4	6.3	12.6
T35	36.7	2.8	13.2	3.4	5.7	9.3	77.0	6.3	6.3	6.2	13.0
T31	37.4	2.7	13.8	2.2	7.6	5.8	130.8	5.9	8.8	6.2	11.7
T34	38.5	3.0	12.7	2.8	13.0	7.2	134.4	5.9	14.2	5.8	18.3
T39	38.8	2.6	15.0	2.6	8.3	6.8	104.7	6.0	11.0	6.3	9.2
T37	39.1	2.8	13.9	2.7	12.7	7.0	103.6	6.6	4.9	6.1	6.1
T09	39.7	2.8	14.3	2.9	6.0	7.3	113.0	6.2	20.4	6.3	18.3
T08	39.9	3.5	11.3	2.7	7.2	6.8	143.9	7.0	10.5	6.0	7.0
T22	40.4	2.7	14.8	2.8	10.7	6.9	107.6	6.6	8.8	6.6	10.8
T40	41.2	3.0	13.7	2.8	7.5	6.8	107.0	6.9	7.5	5.9	11.7
T13	41.8	3.6	11.6	2.5	7.6	6.0	130.2	6.2	7.6	5.9	12.3
T02	42.0	3.1	13.4	3.3	6.7	7.7	139.9	7.3	9.1	6.4	10.9
T11	42.0	3.4	12.3	2.5	7.2	5.8	80.4	6.1	13.5	5.9	10.2
T14	42.4	3.1	13.6	2.9	8.7	6.9	106.2	5.9	12.1	6.5	6.5
T28	42.4	3.3	12.8	2.8	16.0	6.7	153.0	6.7	10.9	5.3	13.6
T12	43.1	3.5	12.5	2.7	8.0	6.2	93.8	6.6	8.7	6.5	8.8
T38	43.4	3.2	13.6	3.5	14.6	8.0	153.6	6.4	10.7	6.0	11.3
T27	44.4	2.6	16.8	3.8	15.2	8.5	116.8	6.8	10.3	6.5	10.4
T01	45.6	3.0	15.0	3.5	7.7	7.6	110.7	6.5	10.0	6.8	10.2
T25	46.6	3.2	14.5	3.2	8.7	6.8	189.2	6.4	13.3	4.7	15.2
T26	48.1	3.5	13.8	3.7	10.5	7.8	121.2	6.4	18.5	6.3	14.9
T15	51.5	4.4	11.8	3.6	9.5	7.0	190.1	6.1	12.8	6.0	6.8
T21	51.5	4.1	12.6	3.6	16.8	7.0	144.4	6.8	8.8	5.1	13.3
T06	54.8	3.9	14.2	3.6	10.2	6.5	153.8	5.4	33.1	6.2	7.2
T16	61.7	5.3	11.6	3.4	9.7	5.5	118.5	5.3	10.8	5.1	10.5
T05	63.0	6.0	10.4	3.9	12.6	6.2	150.1	5.7	18.8	5.8	11.0
T29	68.1	4.4	15.4	4.7	23.7	6.9	123.4	6.4	9.2	5.8	12.4
T33	75.4	5.3	14.1	4.7	11.8	6.3	186.6	5.6	16.4	5.3	19.8
Mean	**43.5**	**3.3**	**13.5**	**3.0**	**9.3**	**7.0**	120.4	**6.4**	**12.0**	**6.1**	**11.2**
T17-1	58.7	4.4	13.5	**3.8**	**10.1**	**6.5**	195.1	5.7	10.3	6.3	6.3
T18-1	66.1	5.7	11.6	**3.7**	**10.1**	**5.6**	144.0	4.9	11.9	5.3	5.0
T19-1	63.4	5.6	11.4	**4.0**	**10.3**	**6.3**	223.6	5.3	15.4	5.9	4.5
T20-1	65.0	5.6	11.7	**5.4**	**6.5**	**8.4**	312.9	5.7	19.7	6.5	6.6
T36-1	45.6	3.0	15.0	**3.8**	**10.1**	**6.5**	-	5.7	17.7	6.0	-
Mean	**63.3**	**5.3**	**12.0**	**4.2**	**9.3**	**6.7**	**218.9**	**5.5**	**15.0**	**6.0**	**5.6**

* Soil tests conducted by Phil Moody, Department of Natural Resources, Qld

** Total C levels are sorted in ascending order

The reference sites have the descriptor '-1' at their end for ease of identification.

Total C

C1 comprised less than 10% of the total organic C found in the soils, indicating that a high proportion of the total soil carbon is relatively stable carbon that is resistant to oxidation.

Table 4.6: Analytical tests of Victorian & NSW soil cores taken from 0-150 mm depth for carbon, nitrogen, pH and electrical conductivity.

	Depth 0-15 cm						MBC	Depth 0-15 cm		Depth 45-60 cm	
	Total C	Total N	C:N	C1	C3	C1/ Tot C	(mg/kg)	pHw	EC	pHw	EC
Vic											
V2	2.8	0.4	7.4	0.3	0.5	10.4	16.6	8.5	5.5	7.1	3.2
V3	3.4	0.4	8.1	0.4	0.4	10.6	13.3	8.3	6.8	7.0	4.9
V4	3.7	0.5	7.1	0.4	0.5	11.1	17.6	7.7	7.7	6.3	4.9
mean	3.3	0.4	7.5	0.4	0.4	10.7	15.8	8.2	6.7	6.8	4.4
V1-1	13.3	1.6	8.3	1.4	1.9	10.2	70.6	5.9	5.7	6.9	2.0
NSW											
N1	8	1.3	6.3	0.7	1.2	8.5	52.3	7.3	66.0	8.2	44.7
N2	10.2	1.2	8.2	0.8	1.5	8.2	36.6	6.2	30.1	8.8	50.9
N3	8.8	0.9	10.1	0.8	1.7	9.3	82.7	6.1	30.8	N/a	N/a
mean	9.0	1.1	8.2	0.8	1.5	8.7	57.2	6.6	42.3	8.5	47.8
N4-1	16.5	1.5	11.3	1.6	2.8	9.5	149.7	6.7	20.4	8.2	150.4
N5	9	1.3	7.0	0.7	1.2	7.7	47.2	8.5	37.2	9.0	20.3
N6	8.4	1.2	6.9	0.6	1.1	7.0	53.1	8.1	44.9	8.8	20.2
N7	9.3	1.0	9.8	0.7	1.2	7.3	25.4	7.9	36.2	8.2	27.9
mean	8.9	1.1	7.9	0.7	1.1	7.3	41.9	8.2	39.4	8.7	22.8
N8-1	13.9	1.4	10.1	1.3	2.6	9.2	100.9	6.8	7.2	8.5	22.5

* Soil test conducted by Phil Moody, Department of Natural Resources, Qld

The reference sites have the descriptor '-1' at their end for ease of identification.

In Tasmanian cropped soils, the total C ranged from 2.45% to 7.54% (i.e. 24.5 to 75.4 g/kg soil), with an average of 4.35%. The wide range in total C in the cropped sites did not appear to be related to the cropping history (intensive vs intermediate). This suggests that apart from cropping history, other factors such as crop type, rotation crops, and soil management might also have influenced soil carbon levels.

All carrot sites had lower total C and total N contents than reference sites, and this difference was greatest for the Victorian sites. Compared to NSW and Victoria, the total C and total N in the Tasmanian cropped sites was relatively high. The Total C in cropped sites ranged from 0.8% to 1.0% in NSW, and 0.3% to 0.4% in Victoria. The Tasmanian sites had much greater C and N contents (**Table 4.6**). One reason for this is that cooler temperatures result in lower turnover rates of organic matter. The different soil types may also be a contributing factor to the differences, as soils with greater clay contents tend to retain greater levels of organic carbon.

Labile C1 & C3

The differences in the labile carbon (C1 values) followed a similar pattern to total C and total N, i.e. all carrot sites had lower C1 contents than reference sites and Tasmanian sites had the highest levels. The pattern for C3 was similar in Victoria and NSW but there was no such trend in the Tasmanian data. The ratio of C1 to total C was lowest in Tasmania but the absolute amounts were highest.

In Tasmania, the cropped sites generally had higher C:N ratios than reference sites. In contrast, the reverse trend applied to NSW and Victorian sites. The ratio of C to N gives an indication of the capacity of a soil to mineralise N. Typically, the C:N ratio of soils is approximately 10 to 1, with some variation according to soil texture and climatic region. Higher ratios may indicate recent incorporation of plant residues or manure.

Microbial biomass carbon (MBC)

In Tasmanian soils (reference and cropped sites), simple linear regression showed that there is a positive relationship between Total C and MBC ($p < 0.01$, $R = 0.65$) (**Figure 4.4**). The level of C1 followed a similar trend, with a positive relationship between C1 and MBC ($p < 0.01$, $R = 0.71$) (**Figure 4.5**).

Figure 4.4: Plot of Total C vs MBC

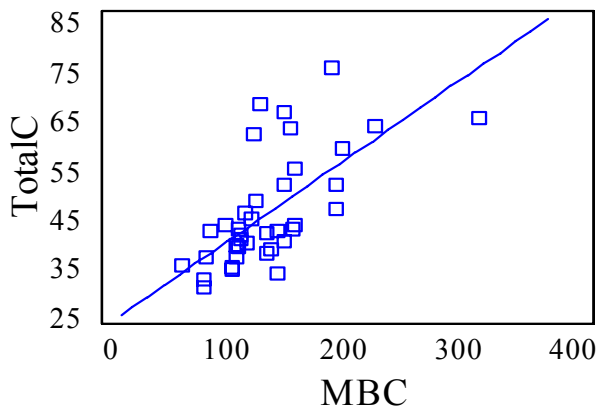
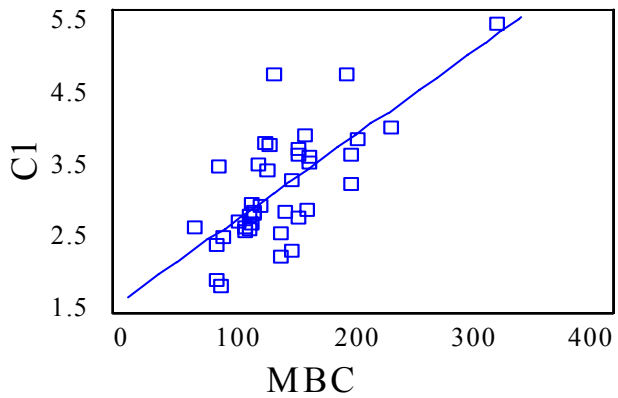


Figure 4.5: Plot of C1 vs MBC

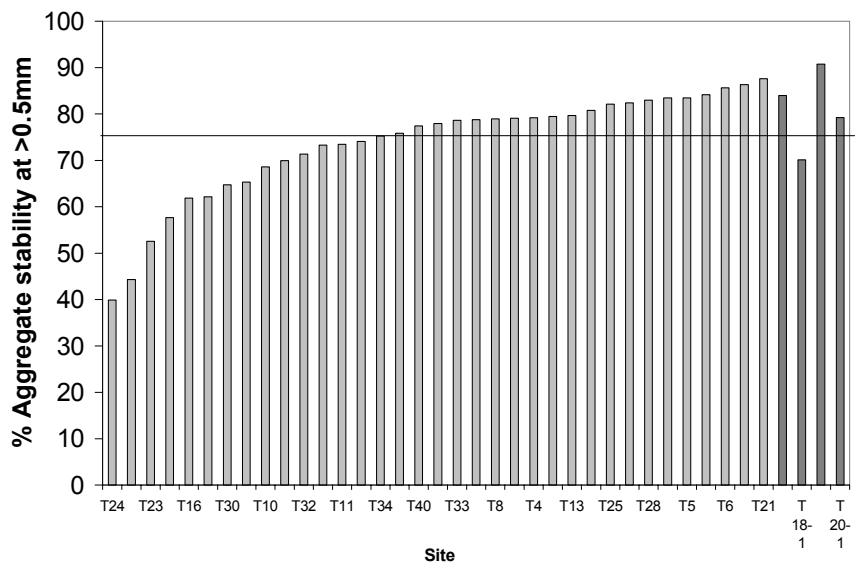


Aggregate stability

The aggregate stability of carrot soils in Tasmania ranged from 40% to 88%, with an average of 74% ± 12%, while the aggregate stability of reference soils in Tasmania ranged from 70% to 91%, with an average of 81% ± 9% (**Figure 4.6**).

The majority of the carrot sites in Tasmania had relatively high soil aggregate stabilities. Only 4 sites had relatively low aggregate stability of less than 60%.

Figure 4.6: Aggregate stability of carrot soils and reference soils in Tasmania*



*** Aggregate stability of carrot soils sorted in ascending order.**
Reference sites denoted by the dark coloured bars

pH and EC values

In all three states, the carrot sites had higher pH in the soil at 0-150 mm than the reference sites, indicating a history of lime application. Tasmanian sites had the lowest pH. Carrot sites in NSW were slightly alkaline; in Victoria they were alkaline and in Tasmanian the sites were slightly acidic. Subsoils (450-600mm) in Tasmania and Victoria were neutral to slightly acidic, and in NSW they were alkaline.

EC values in Tasmania and Victoria are considered to have no impact on carrot yield. However, EC values on NSW carrot sites indicate that high salinity can affect crop yield (critical range of EC 30 – 66 mS/m, EC_{SE} 2.4 – 7.9 depending on soil texture).

4.1.5 Soil nematodes

Soil nematodes can be divided into two groups: 1) free-living and 2) plant parasitic nematodes (**Tables 4.6 & 4.7**). Both groups of nematodes are found in all soils, whether they are undisturbed pastures or crop soils that are periodically disturbed.

Table 4.6: Free-living and plant parasitic nematodes extracted from soils in Victoria and NSW *

	Nematode population (No. of nematodes / 200 g soil)									
	Saprophytic or free living nematodes				Plant parasitic nematodes					
Site	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
V2	60	900	3	963	0	0	6	93	0.1	-
V3	160	1240	9	1409	0	0	11	88	0.1	-
V4	0	560	34	594	0	0	0	94	0.0	-
Mean	73	900	15	989	0	0	6	92	0.1	-
V1-1	1160	3950	85	5195	0	0	22	76	0.3	-
					0	0				
N1	500	740	2	1242	880	952	40	60	0.7	1
N2	1400	1080	11	2491	40	140	56	43	1.3	18
N3	470	830	0	1300	0	24	36	64	0.6	52
Mean	790	883	4	1678	307	372	44	56	0.8	24
N4-1	100	20	63	183	20	20	55	11	5.0	9
N5	40	540	2	582	0	0	7	93	0.1	-
N6	320	330	0	650	0	0	49	51	1.0	-
N7	640	900	1	1541	12	12	42	58	0.7	119
Mean	333	590	1	924	12.0	4.0	33	67	0.6	119
N8-1	520	400	42	962	720	720	54	42	1.3	1

* Soil test for nematodes conducted by Marcelle Stirling, Biological Crop Protection Pty Ltd.
The reference sites have the descriptor '-1' at their end for ease of identification.

Among the free-living nematodes (FLN), omnivorous nematodes (nematodes that feed on other nematodes, fungi, algae or other soil organisms) were most susceptible to cultivation. Their average population in cropped soils in Tasmania was 9 times lower than in non-cropped pasture soils from reference sites. In contrast, populations of fungal-feeding nematodes (FFN) and bacterial-feeding nematodes (BFN) were only 3.4 and 1.8 times lower, respectively. Similar trends were noted in Victorian and NSW soils, except for unusually low FFN and BFN in the reference site N4-1 in NSW. In contrast to Omniv and FFN, cultivation tended to have less impact on BFN, which have short life cycles and can multiply rapidly following a disturbance in soil.

Generally, populations of plant parasitic nematodes were much lower in cropped soils than in non-cropped reference soils (**Tables 4.6 & 4.7**), probably because a large biomass of plant roots is always present in pastures. This does not necessarily mean that losses in production from nematodes were occurring in pasture, as some of the nematodes that are present (e.g. *Paratylenchus*) are not very pathogenic.

Table 4.7: Free-living and plant parasitic nematodes extracted from soils in Tasmania*

Nematode population (No. of nematodes / 200 g soil)

Site	Saprophytic or free living nematodes				Plant parasitic nematodes					
	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	%FFN	%BFN	FF/BF	FLN/Para
T01	1020	2140	16	3176	100	100	32	67	0.5	31
T02	255	375	2	632	20	20	40	59	0.7	30
T03	465	1490	4	1959	64	64	24	76	0.3	30
T04	600	1450	3	2053	2	2	29	71	0.4	684
T05	670	1280	1	1951	190	190	34	66	0.5	10
T06	800	1350	13	2163	360	360	37	62	0.6	5
T07	290	850	3	1143	120	120	25	74	0.3	9
T08	860	880	6	1746	560	560	49	50	1.0	3
T09	1250	1680	4	2932	160	160	43	57	0.7	13
T10	460	1380	5	1845	180	180	25	75	0.3	10
T11	310	1025	6	1341	20	20	23	76	0.3	64
T12	335	315	11	661	0	0	51	48	1.1	661
T13	545	1140	4	1689	140	140	32	67	0.5	12
T14	2270	1450	24	3744	160	160	61	39	1.6	23
T15	265	320	5	590	10	10	45	54	0.8	54
T16	415	240	18	673	740	740	62	36	1.7	1
T21	320	1000	23	1343	0	0	24	74	0.3	1343
T22	400	840	0	1240	0	0	32	68	0.5	1240
T23	84	2040	21	2145	32	32	4	95	0.0	65
T24	860	740	22	1622	0	0	53	46	1.2	1622
T25	1120	880	28	2028	60	60	55	43	1.3	33
T26	480	2560	13	3053	80	80	16	84	0.2	38
T27	1260	900	8	2168	0	0	58	42	1.4	2168
T28	400	440	5	845	0	0	47	52	0.9	845
T29	1860	800	29	2689	140	140	69	30	2.3	19
T30	707	2160	16	2883	180	180	25	75	0.3	16
T31	1040	1500	25	2565	0	0	41	58	0.7	2565
T32	620	800	9	1429	0	0	43	56	0.8	1429
T33	1300	7700	20	9020	0	0	14	85	0.2	9020
T34	880	3150	18	4048	120	120	22	78	0.3	33
T35	2200	1700	65	3965	160	160	55	43	1.3	25
T37	820	720	20	1560	320	320	53	46	1.1	5
T38	460	480	32	972	0	0	47	49	1.0	972
T39	1648	1900	30	3578	0	0	46	53	0.9	3578
T40	180	860	18	1058	0	0	17	81	0.2	1058
Mean	**784**	**1387**	**15**	**2186**	**112**	**112**	**38**	**61**	**0.7**	**792**
T17-1	1210	560	86	1856	1600	1600	65	30	2.2	1
T18-1	4160	3250	78	7487	1600	1600	56	43	1.3	2
T19-1	2250	2900	208	5358	1200	1200	42	54	0.8	3
T20-1	1550	3650	130	5330	2400	2400	29	68	0.4	2
T36-1	4000	2050	210	6260	500	500	64	33	2.0	12
Mean	**2634**	**2482**	**142**	**5258**	**1460**	**1460**	**51**	**46**	**1.3**	**4**

* Soil test for nematodes conducted by Marcelle Stirling, Biological Crop Protection Pty Ltd.
The reference sites have the descriptor '-1' at their end for ease of identification.

Table 4.8: Microbiological test results for total microbial activities, bacteria and fungi by the three different laboratories on Tasmanian soils

	Biological Crop Protection Pty Ltd						CSIRO laboratory – PL-FAME method							DNR-Qld laboratory
	FDA hydrolysis (u/g/min)	Log10 cfu microbes per g dry soil; cfu = colony forming unit					ug/g soil							(mg/kg)
Site	FDA (Total microbial activity)	Total bacteria	Total Gram + bacteria	Fluo. Pseu. bacteria	Total fungi	Actino	Total PL-FAMEs (Total microbial activity)	Total bacteria	Gram+ve bacteria	Gram-ve bacteria	Fungi	Mycorrhizal fungi	Ratio fungi:bact.	**MBC**
T01	1.5	7.9	6.9	4.3	4.0	6.4	7.1	1.97	1.25	0.72	0.11	0.17	0.05	79.8
T02	0.8	7.2	6.9	4.0	4.2	6.2	4.5	1.26	0.85	0.41	0.08	0.16	0.06	75.8
T03	0.7	7.4	6.5	5.4	4.7	6.4	9.2	2.67	1.69	0.98	0.27	0.26	0.10	75.8
T04	0.9	7.3	7.3	4.5	5.4	6.9	6.8	2.03	1.33	0.69	0.14	0.17	0.07	139.6
T05	0.9	8.5	7.3	4.6	5.4	7.5	11.2	3.53	2.25	1.28	0.10	0.18	0.03	99.6
T06	0.6	6.9	6.3	4.3	5.3	6.7	13.1	3.98	2.50	1.48	0.20	0.21	0.05	99.2
T07	1.3	6.9	6.4	3.5	5.7	7.3	5.4	1.74	1.16	0.58	0.08	0.11	0.04	56.8
T08	1.0	7.3	7.3	3.8	4.8	7.3	10.9	3.40	2.20	1.20	0.10	0.18	0.03	103.6
T09	1.0	8.0	6.0	4.1	5.7	7.2	5.4	1.91	1.23	0.69	0.10	0.11	0.05	77.0
T10	0.8	8.5	7.0	5.5	3.8	7.3	4.4	1.23	0.71	0.53	0.06	0.17	0.05	130.8
T11	0.8	8.3	6.7	3.1	5.0	6.5	5.6	1.66	1.09	0.57	0.05	0.09	0.03	134.4
T12	0.8	6.8	5.6	3.6	4.7	6.5	6.6	1.98	1.30	0.68	0.07	0.11	0.03	104.7
T13	2.3	6.4	5.7	4.2	5.3	6.5	7.8	2.35	1.54	0.82	0.05	0.12	0.02	103.6
T14	0.9	6.4	5.9	2.0	4.9	6.4	9.7	2.80	1.85	0.96	0.10	0.18	0.03	113.0
T15	1.1	6.6	6.2	4.1	5.6	6.4	12.1	3.73	2.36	1.37	0.19	0.24	0.05	143.9
T16	0.3	7.8	6.5	3.9	6.1	7.2	10.9	3.35	2.14	1.20	0.08	0.15	0.02	107.6
T21	2.5	8.0	7.3	4.3	5.2	7.7	10.6	3.17	1.99	1.18	0.07	0.26	0.02	107.0
T22	0.9	8.7	8.5	3.8	5.4	7.1	4.5	1.51	1.01	0.50	0.00	0.00	0.00	130.2
T23	1.9	7.7	7.5	5.9	4.4	7.7	5.1	1.79	1.17	0.62	0.03	0.08	0.02	139.9
T24	1.0	7.6	6.6	3.5	6.3	5.7	2.2	0.78	0.49	0.29	0.00	0.04	0.00	80.4
T25	1.6	6.1	4.6	4.1	5.0	6.9	0.0	0.00	0.00	0.00	0.00	0.00	0.00	106.2
T26	1.8	7.5	6.5	5.8	5.6	6.6	4.2	1.28	0.77	0.51	0.03	0.07	0.02	153.0
T27	0.9	7.7	7.5	4.8	4.6	8.9	4.5	1.40	0.92	0.48	0.04	0.09	0.03	93.8
T28	1.6	5.5	4.5	4.2	5.1	6.7	0.0	0.00	0.00	0.00	0.00	0.00	0.00	153.6
T29	1.9	9.4	8.0	6.3	5.9	7.5	5.7	1.75	1.11	0.64	0.04	0.13	0.23	116.8
T30	1.8	7.9	7.3	5.6	4.4	6.5	2.4	0.82	0.53	0.29	0.00	0.04	0.00	110.7
T31	1.9	7.8	6.1	5.6	6.0	6.7	2.7	0.89	0.58	0.31	0.03	0.05	0.03	189.2
T32	0.8	7.6	6.7	3.2	4.7	8.1	3.0	0.94	0.62	0.32	0.00	0.05	0.00	121.2
T33	2.5	7.4	7.1	3.6	5.4	7.4	4.8	1.49	1.07	0.42	0.04	0.08	0.03	190.1
T34	2.5	7.5	6.7	4.6	5.4	7.3	3.8	1.25	0.74	0.51	0.03	0.07	0.02	144.4
T35	1.1	8.9	7.4	5.6	5.4	7.6	5.4	1.65	1.05	0.60	0.14	0.12	0.08	153.8
T37	1.5	7.9	7.3	4.2	5.4	8.7	2.5	0.84	0.56	0.28	0.04	0.06	0.05	118.5
T38	3.0	8.5	6.9	4.3	5.5	8.1	5.0	1.54	1.01	0.53	0.03	0.10	0.02	150.1
T39	2.8	8.3	7.1	4.3	5.5	8.0	5.6	1.82	1.23	0.59	0.09	0.12	0.05	123.4
T40	1.5	8.7	7.0	4.4	4.8	7.3	3.9	1.32	0.83	0.49	0.05	0.08	0.04	186.6
mean	**1.4**	**7.6**	**6.7**	**4.4**	**5.2**	**7.1**	**5.9**	**1.82**	**1.18**	**0.65**	**0.07**	**0.12**	**0.04**	**120.4**
T17-1	3.2	7.9	7.7	6.8	6.5	7.9	16.3	5.27	3.27	2.00	0.17	0.24	0.03	195.1
T18-1	4.1	7.0	5.9	3.6	5.6	7.2	12.7	3.89	2.20	1.69	0.17	0.20	0.04	144.0
T19-1	2.6	8.2	6.0	6.2	5.6	6.8	12.8	3.74	2.28	1.46	0.14	0.23	0.04	223.6
T20-1	4.0	7.6	6.8	5.8	5.7	7.3	20.2	6.31	3.21	3.10	0.40	0.35	0.06	312.9
T36-1	4.6	9.2	7.5	5.5	5.4	6.8	19.2	4.81	3.07	1.74	0.47	0.76	0.10	-
mean	**3.7**	**8.0**	**6.8**	**5.6**	**5.8**	**7.2**	**16.2**	**4.80**	**2.81**	**2.00**	**0.27**	**0.36**	**0.05**	**218.9**

The reference sites have the descriptor '-1' at their end for ease of identification.

Table 4.9: Microbiological test results for total microbial activities, bacteria and fungi by the three different laboratories on soils from Victoria and NSW

	Biological Crop Protection Pty Ltd						CSIRO laboratory							DNR-Qld laboratory
	FDA hydrolysis (u/g/min)	Log10 cfu microbes per g dry soil; cfu = colony forming unit					ug/g soil							(mg/kg)
Site	FDA (Total microbial activity)	Total bacteria	Total Gram + bacteria	Fluo. Pseu. bacteria	Total fungi	Actino	Total PL-FAMEs (Total microbial activity)	Total bacteria	Gram+ve bacteria	Gram-ve bacteria	Fungi	Mycorrhizal fungi	Ratio fungi:bact.	**MBC**
V2	0.10	7.7	6.8	5.4	4.2	5.7	0.58	0.17	0.14	0.03	0.00	0.00	0.00	16.6
V3	0.14	8.3	7.3	4.9	4.5	4.8	0.54	0.15	0.11	0.03	0.00	0.00	0.00	13.3
V4	0.16	8.0	7.2	5.2	5.4	5.9	0.80	0.26	0.19	0.06	0.01	0.00	0.03	17.6
Mean	**0.13**	**8.0**	**7.1**	**5.2**	**4.7**	**5.5**	**0.64**	**0.19**	**0.15**	**0.04**	**0.00**	**0.00**	**0.01**	**15.8**
V1-1	0.56	8.3	6.7	4.4	4.8	5.9	1.05	0.31	0.21	0.10	0.00	0.00	0.00	70.6
N1	0.15	8.5	6.5	4.6	5.2	6.7	4.51	1.30	0.93	0.37	0.05	0.09	0.04	52.3
N2	0.07	8.7	6.3	2.9	4.7	7.7	2.44	0.73	0.50	0.23	0.04	0.05	0.05	36.6
N3	0.13	7.2	5.7	3.4	4.7	6.2	5.79	1.76	1.36	0.40	0.05	0.11	0.03	82.7
Mean	**0.12**	**8.2**	**6.2**	**3.6**	**4.9**	**6.9**	**4.25**	**1.26**	**0.93**	**0.33**	**0.05**	**0.08**	**0.04**	**57.2**
N4-1	0.64	8.3	5.7	5.5	5.5	6.8	5.54	1.41	0.96	0.45	0.16	0.18	0.11	149.7
N5	0.08	8.1	6.3	3.1	5.2	6.2	5.09	1.19	0.95	0.24	0.07	0.10	0.05	47.2
N6	0.05	8.1	6.0	3.8	4.4	6.3	3.97	1.51	1.20	0.31	0.07	0.11	0.05	53.1
N7	0.96	6.5	6.0	3.2	5.3	6.4	2.50	0.63	0.45	0.18	0.02	0.06	0.03	25.4
Mean	**0.37**	**7.6**	**6.1**	**3.4**	**5.0**	**6.3**	**3.85**	**1.11**	**0.87**	**0.24**	**0.05**	**0.09**	**0.04**	**41.9**
N8-1	1.01	7.7	2.4	7.2	4.9	6.9	4.46	1.09	0.76	0.33	0.08	0.10	0.07	100.9

The reference sites have the descriptor '-1' at their end for ease of identification.

4.1.6 Soil microbiological analysis

In general, the microbial status of the soil was higher in the reference sites than in the crop sites, regardless of the different methodologies used at the three laboratories (**Tables 4.7 - 4.10**). The analyses involved included total microbial activity measured using the PL-FAME method (CSIRO laboratory, Adelaide), hydrolysis of fluorescein diacetate or FDA (Biological Crop Protection laboratory, Brisbane), and microbial biomass carbon or MBC measured using the microwave irradiation method (Department of Natural Resources, Qld). The MBC values are presented in sub-section 4.1.4 on soil carbon.

In simple linear regression, there are positive relationships between total C and PL-FAME ($p < 0.01$, $R = 0.57$), and total C and MBA-FDA ($p < 0.01$, $R = 0.43$) in Tasmanian soils, including reference and cropped soils (**Figures 4.7 & 4.8**)

Figure 4.7: Plot of Total C vs Total PL-FAME

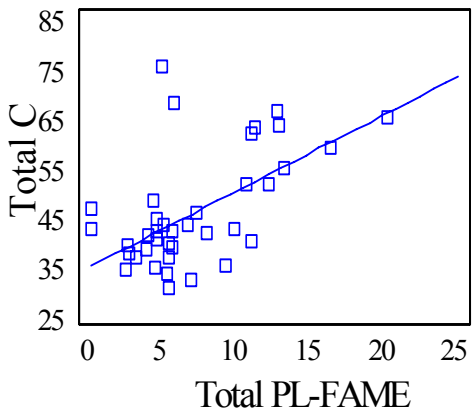
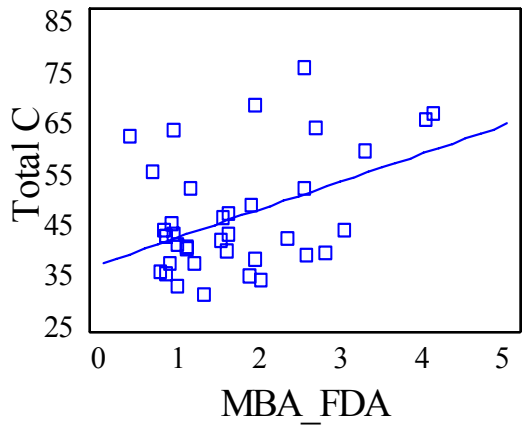


Figure 4.8: Plot of Total C vs MBA_FDA



The level of C1 followed a similar trend to Total C, with positive relationships between C1 and PL-FAME ($p < 0.01$, $R = 0.54$), and between C1 and MBA-FDA ($p < 0.01$, $R = 0.45$) (**Figures 4.9 & 4.10**).

Figure 4.9: Plot of C1 vs Total PL-FAME

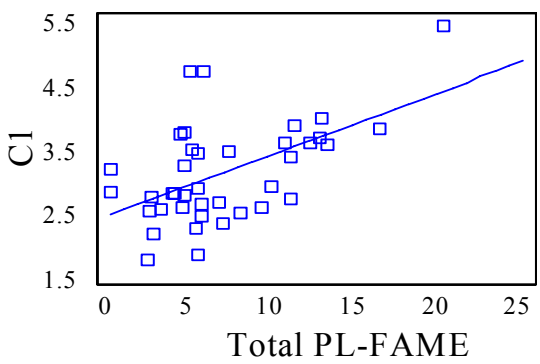
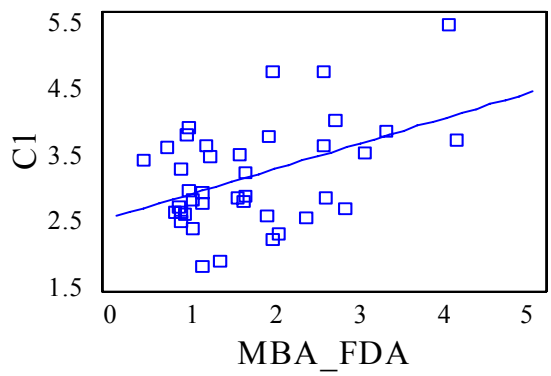


Figure 4.10: Plot of C1 vs MBA_FDA



The differences in other microbiological parameters, such as omnivorous nematodes, total bacteria and fungi, gram +ve bacteria, mycorrhizal fungi and the labile carbon (C1) values, followed a similar pattern to total microbial activity and biomass, i.e. all carrot sites had lower values than reference sites.

Table 4.10 Comparison of potential soil health indicators, which were significant in the matrix of all possible pair-wise simple correlation coefficients for data values collected from the cropped and reference soils in Tasmania.

	Total N	Total C	C1	C3
Nematode extraction	FFN	FFN	FFN	%FFN
	BFN	BFN	BFN	%BFN(-)
	Omniv	Omniv	Omniv	FF:BF
	FLN	FLN	FLN	
	Lesion	Lesion	Lesion	
	Parasitic	Parasitic	Parasitic	
Fluorescine diacetate hydrolysis	FDA	FDA	FDA	
Colony forming unit count			Fluo. Pseu	Actino
Microbial biomass C or organic carbon	MBC	MBC	MBC	
PL-FAME analysis	Total bacteria	Total bacteria	Total bacteria	
	G+ bacteria	G+ bacteria	G+ bacteria	
	G- bacteria	G- bacteria	G- bacteria	
	Fungi	Fungi	Fungi	
	Mycorrhizal fungi	Mycorrhizal fungi	Mycorrhizal fungi	
	Total PL-FAMEs	Total PL-FAMEs	Total PL-FAMEs	
			Ratio fungi:bacteria	
Chemical analysis	Total C(-)		Total C	Total C
	C1	C1	C3	C1
	C3	C3	Total N	Total N
	C1/Total C(-)	Total N(-)		

A comparison of potential soil health indicators from the matrix of all possible pair-wise simple correlations showed the measurements that were significantly correlated with soil nitrogen, carbon, and labile carbons. With the exception of C3, many biological and chemical measurements were closely interrelated with one another (**Table 4.10**). This indicates that relatively common and simple types of tests, e.g. total carbon, total nitrogen, and total free-living nematodes, could be as effective as more complex or time-consuming methods, eg PL-FAME analysis, colony forming unit count, and microbial biomass carbon.

4.1.7 Descriptive information from survey questionnaire

Limited information could be drawn from most of the responses given in the grower survey questionnaire. Much of the field information was based on descriptive and qualitative scorecard type responses provided by growers on soil health. Details of responses are given in Appendix 7. There is a lack of correlation or trends between many of the related qualitative responses and the measured quantitative soil properties. This highlights the severe limitations with the descriptive soil health and crop health score system (mostly based on score rating of 1-3, or yes and no replies), with their narrow frame of reference. This is in contrast to the wide definition of soil health and the complexity of many interconnected factors that impact on it.

Furthermore, many growers also tend to reflect only on issues that directly affect crop production, and often fail to recognise critical aspects of soil health with respect to environmental protection, water use and the overall impact in farm management. For example, some growers believed that soil decline is not major issue on their properties, as there has been no obvious decline in crop yield. However, these growers also recorded an increased use of soil fumigation, pesticides, fertilisers and irrigation over the last five years. The use of crop yield as a measure of soil decline can be misleading as yield decline can be offset by yield increases due to introduction of high yielding new varieties, salt tolerant varieties, better fertiliser application, better disease and pest control, and improved technology in farm management.

Some carrot growers in South Australia and Victoria were also surveyed in this study on their perception of soil health on their properties. All of the growers expressed their great interest in soil health issues and sustainable land use. Soil fumigation with metham sodium was commonly used in South Australia prior to carrot production, but was rarely used by the Victorian growers. However, when asked specific questions used in the questionnaire on soil health, the replies given for one question were often contradictory to those given in another. While many growers perceived that soil decline was not a major issue on their property, these views were often in conflict to other issues that are related to soil health, e.g. feedback that carrot yields are affected by soilborne diseases, mishappen carrots and topsoil salinity. Increased use of irrigation, fertiliser, fungicide, fumigation, and insecticides were also recorded. These findings highlight the limitation of the survey questionnaire, and that the types of questions asked may need to be reviewed. The conflicting responses also suggest a lack of understanding of the underlying factors that impacts on the overall soil health, and that greater dialogue is required between growers and scientists to advance our collective understanding on the definition of soil health. However, as many scientists themselves are still in the process of understanding factors that impact on soil health, soil sampling and analytical measurements are essential as a basis for improving our understanding.

4.2 Discussion

4.2.1 Carrot production and soil conditions

This study showed that the soil factors identified as having the greatest influence on carrot production were related to soil structure. This is not surprising, as the appearance of carrots produced for the fresh market is highly critical. The tap root of carrot at an early growth stage is highly susceptible to adverse soil structural conditions. The main factors associated with reduced carrot packout or quality in Ferrosol soils in Tasmania, were total soil carbon, numbers of misshapen carrots and levels of disease (particularly crown rot disease).

Soil physical condition can be divided into static and changeable properties. The first consists of properties such as soil profile, morphological features, and textures that are relatively static and do not change readily with agricultural practices. The second part includes penetration resistance, bulk density, and aggregate stability, which are subject to measurable changes with different management practices. These are the indicators of changes in soil physical quality, and can be used to indicate positive or negative changes. Among these indicators, soil penetration resistance is easy to measure in the field.

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. In Tasmania, penetration resistance in the topsoil (0-300 mm) is highly dependent on soil moisture. There was no correlation between misshapen carrots and penetration resistance readings in soils from Tasmania. An explanation for this lack of relationship is that unlike a rigid penetrometer, a root can diverge from its direct line of advance when a resistant aggregate (e.g. small hard clod) is in its way. A study conducted by Ehlers *et al.* (1983) showed that in conventionally tilled soil, root growth was severely restricted at a penetrometer pressure of 3600 kPa; while in untilled soil, the corresponding limit was at about 5000 kPa. In the untilled soil, the roots by-passed the resistant barriers using channels left by earthworms and decayed roots that were not preserved in the tilled soil.

The positive correlation between misshapen carrots and total number of passes with a rotary hoe, could be taken as an indication of impeded root growth caused by the close packing of resistant soil aggregates. The number of passes required could be indicative of soil structural decline, where a poor soil requires more passes with a rotary hoe to generate suitable soil conditions for carrot production. Soil preparation for a fine tilth could help reduce the density of resistant soil aggregates and therefore reduce the percentage of misshapen carrots. Misshapen carrots are a common problem in carrot crops in Tasmania, with losses ranging from 0.3% to 19.5%, and an average loss of 8.2%. These figures do not include forked carrots, which could be caused by root pathogens or plant parasitic nematodes, as well as soil physical properties.

Penetration resistance at 150-300 mm was negatively correlated to carrot yield and positively correlated to the percentage of diseased carrots at 0-150 mm. These relationships, however, are likely to be through indirect effects on the soil environment, on deep root development and by the creation of favourable conditions for root pathogens. Apart from misshapen carrots, carrot root disease is the other major cause of loss in carrot packout.

The direct link between diseased carrots and topsoil penetration resistance and topsoil erosion suggested that disease development is influenced by soil structural properties. Slow water infiltration with some run-off or ponding was recorded in 50% of the sites surveyed in Tasmania. Wet soil conditions and slow infiltration favour many root pathogens. Growers often overlook the impact of temporary flooding and the prolonged period of saturation that can occur following heavy rainfall or overhead irrigation in soil with structural decline.

The focus of most plant disease control programs is on controlling the pathogen with pesticides. Yet, many soilborne pathogens, such as *Sclerotinia, Rhizoctonia,* and *Phytophthora* are

extremely difficult to control by chemical methods. If successful, the chemical control methods usually offer only a temporary solution, requiring multiple or repeated applications for control.

The presence of these pathogens, however, does not necessarily pose a threat to crop production. The ultimate impact that these pathogens have on plants will depend on a favourable soil environment for the pathogens. This dependency could provide an opportunity to modify soil conditions with different management practices for long-term control through suppression of soilborne pathogens.

The soil depth where the maximum penetration resistance occurred at the cropped sites in Tasmania and NSW exceeded 500 mm. This suggests that depth of the hard pan is unlikely to be a limiting factor for plant roots.

Total carbon in soils has a positive correlation to carrot quality and packout. Soil carbon has effects on key soil physical, chemical and biological properties. Although labile or readily oxidisable carbon is believed to be the key quality factor of soil, the importance of stable carbon is not to be underestimated. Apart from management practices, soil texture and climatic conditions also affect carbon, hence making it inappropriate to compare carbon values across different climatic conditions and landscape. References to non-cropped reference soils, however, may provide some indication of carbon depletion. In Tasmania, the average total carbon in cropped sites was 4.35% compared to 6.3% in reference sites. Total carbon was 0.9% and 1.5% in NSW, and 0.3% and 1.3% in Victorian sites, for cropped sites and reference sites, respectively. Similar decline was also recorded with the labile carbon in all states. This suggests that total carbon, which is routinely measured in soil nutrient analysis, may also be a useful soil quality indicator for monitoring changes over time. Yet, growers and consultants often ignore the carbon values in the analysis reports. Soil management practices that help maintain soil carbon can thus be adopted, and practices that result in its decline can be discouraged.

4.2.2 The status of soil health & potential indicators

The term soil health defines a soil's capacity to sustain biological productivity, to maintain environmental quality, and to promote plant, animal and human health. Apart from agricultural use, it encompasses the function of soil as a living filter in breaking down and recycling organic wastes, chemicals, and pollutants, and hence protecting our environment and ensuring clean food production.

Soil organic matter is a reservoir of plant nutrients in soil, 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. A measurement of organic matter itself will not provide sufficient information regarding how it impacts on soil health. Useful information, however, could be obtained by measuring other soil indicators that are influenced by the composition of organic matter and are highly sensitive to changes in management practices.

In this feasibility study, non-cropped soils under long-term pasture or grass are used as ideal benchmarks for comparison with carrot growing soils, to determine soil characteristics that are associated with a decline in soil health. This assumes that the reference soils contain the ideal or desirable characteristics. Some of the important impacts of intensive use of soil for vegetable production on soil health, and the potential use of the relevant soil health indicators are discussed below.

Soil penetration resistance

Penetration resistance was not measured at the reference non-cropped sites, due to vast differences between tilled and non-tilled ground. Therefore, comparisons made between cropped and non-cropped sites are not expected to yield any meaningful information. However, topsoil penetration resistance at 0-150 mm and 150-300 mm were found to have positive correlations with the incidence of diseased and misshapen carrots, respectively. This indicates that this method of soil structural measurement could be useful for determining the potential risk of a soil to root diseases and disorders.

Soil structure score

Based on visual assessments according to soil cloddiness, all reference sites in Tasmania had visibly better structure than the carrot sites. Carrot sites in 2001 had visibly better soil structure score on average compared to those in 2000. In 2000, all cropped sites surveyed were sown in early spring (October/November), while in 2001, the crops were sown in late spring to early summer (December/January). The soil structure score could, therefore, reflect the seasonal period when cultivation for seedbed preparation occurred. Soil cultivation in winter and early spring under wet and cold conditions has greater potential of causing adverse structural degradation. Similarly, harvesting under wet soil conditions can also cause structural decline.

In Tasmania, the soil structure score had a positive correlation to the total number of fallow periods in the previous 5 years, the total number of green manure crops sown in previous 5 years, populations of omnivorous nematodes and populations of total fungi (cfu/g soil). Both omnivorous nematodes and soil fungi are susceptible to soil disturbances, and populations can decline rapidly, and also tend to take longer to recover compared to many other soil organisms. These relationships suggest that the use of a soil structure score could offer a quick, easy and low cost method of assessing soil physical conditions, and the impact of management practices.

Carbon levels

Generally, all the carrot sites had lower carbon levels, i.e. total carbon, C1 and C3, than reference sites in all states. This indicates a general decline in soil carbon levels as a result of land use for vegetable crop production. Apart from soil management practices, other major influences on the levels of carbon in soil are climatic conditions and soil types. For example, the rate of organic matter decomposition and carbon loss into the atmosphere is higher under a warm climate than in a cool, temperate climate. Therefore, the average total carbon levels recorded in cropped sites in Queensland, NSW and Victoria (1.3%, 0.3% and 0.9%, respectively) were much lower than those in Tasmania (4.4%).

Among the carrot sites, total carbon depletion compared to reference sites appeared to occur at a higher rate in NSW (average decline of 41%) and Victoria (75%) than in Tasmania (31%). The corresponding differences in the decline of the labile carbon C1 for NSW, Victoria and Tasmania were 48%, 52% and 9%, respectively between carrot sites and reference sites. This shows that cropped soils in Victoria and NSW face a greater risk of soil degradation through carbon depletion than Tasmanian soils.

Interestingly, the total carbon and C1 levels at some carrot sites in Tasmania were similar to those found in the reference sites. This demonstrates that soil carbon can be maintained on cropped sites. However, as the management practices (e.g. cropping history, crop rotations, and cultivation methods) between different farms were highly variable, it is difficult to pin-point the exact management practices that can help conserve carbon levels and organic matter. There is a trend, however, that among the 7 sites with relatively high levels of total carbon (ranging from 5% to 7%), 5 sites were classified as ‘intermediate’ cropped sites, where pasture, grass, barley, and poppy were sown in rotations with vegetable crops. In addition, 5 of the sites with high carbon also had fallow periods incorporated into the management practice.

Carbon levels in soil tend to change slowly over a long period of time, and consequently any recovery from a decline in carbon level is likely to be an equally slow process. Therefore, strategies for conservation and maintenance of carbon levels must be considered in areas destined for intensive vegetable production.

Total carbon is closely related to C1 and microbial biomass carbon (MBC). This suggests that total carbon, which is often measured in typical soil analysis for plant nutrient elements, could be used as a soil health indicator. If monitored over a long period of 5 to 10 years, it could serve as a useful indicator in identifying management practices that will either prevent or accelerate soil degradation.

As mentioned previously, total carbon in carrot soils had a positive correlation to carrot packout. Thus, even though readily oxidisable carbon like C1 is recognized to be the key indicator of labile soil organic matter, the importance of stable carbon, which is a major component in total carbon, must not to be underestimated.

C:N ratio

The ratio of C to N can provide vital information on nitrogen mineralisation potential and N availability. Depending on soil type, a C:N ratio ranging from 8 to 13 is considered to be desirable for agricultural crops. Crop residues or animal manure application can increase the soil's C:N ratio if the material itself has a high carbon content (e.g. the C:N of wheat straw is 30). Excessive increases in carbon levels to a C:N ratio that is above the desirable level will lead to soil microbial activity, which will compete with plants for nitrogen. Conversely, at a low ratio, the breakdown of organic matter by soil microbes will result in a net mineralisation of nitrogen. Therefore, a good balance of carbon and nitrogen is essential. Two sites in Tasmania appeared to have high C:N ratios of 16.8 and 18.8, respectively.

Aggregate stability

Aggregate stability refers to the resistance of soil aggregates to breakdown by water and mechanical manipulation. Aggregate instability or breakdown by precipitation results in plugging of air pores by fine aggregates or particles and restricts infiltration rate. This may cause surface sealing (soil crusting) and anaerobic conditions.

In Tasmania, the aggregate stability of most carrot soils (average of 74%) was relatively high when compared to reference soils (average of 81%). Out of 34 carrot sites, only 2 sites had relatively low aggregate stability (less than 50%). Therefore, with a few exceptions, the Ferrosol soils in Tasmania are relatively resistant to breakdown.

In contrast, all the capsicum soils in Queensland had aggregate stabilities ranging from 4% to 44%, with an average of 11%. The different soil types, climatic conditions and management practices in the two states may account for the major differences in the soil aggregate stabilities between Tasmania and Queensland. Even so, when compared to similar reference soils in Queensland, the capsicum soils showed substantial decline in the soil aggregate stability, with approximately 80% of the capsicum soils having aggregate stabilities of less than 20%.

Soil nematodes

Soil nematodes can be divided into two groups: 1) free-living and 2) plant parasitic nematodes. Free-living nematodes 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. Free-living nematodes can be further divided into sub-groups according to their feeding habits. Omnivorous predatory nematodes are most susceptible to cultivation. Their average population in cropped soils in Tasmania was 9 times lower than in non-cropped pasture soils from reference sites, compared to average populations of 3.4 and 1.8 times lower for fungal feeding and bacteria feeding nematodes, respectively.

Cultivation and bed preparation are detrimental to omnivorous nematodes, as they are generally large nematodes and are very susceptible to mechanical damage. Their populations also take a longer time to recover from disturbance because they have relatively long life cycles. Some omnivores also feed on fungi, which tend to be scarce in cropped soils. Fungal-feeding nematodes also tend to favour the same soil conditions as omnivorous nematodes. In contrast to its effect on omnivorous and fungal- feeding nematodes, cultivation tends to have less impact

on bacterial-feeding nematodes, which have relatively short life cycles and can multiply rapidly within a short interval.

Generally, plant parasitic nematodes are susceptible to soil disturbance, and their population densities tend to be much lower in cropped soils than in non-cropped reference soils. However, the plant parasitic nematode population can be higher in some cropped sites compared to others. The population differences could be due to the suitability of host plants to the parasitic nematodes. Almost all plant parasitic nematodes extracted in carrot soils were root lesion nematodes. The ability of root lesion nematodes to inflict economic damage to crops is dependent on the species involved, host specificity, and high populations. Root lesion nematode populations can increase during fallow, pasture or pyrethrum rotations when the soil is left undisturbed. Root-knot nematodes that are damaging to carrots, even at relatively low populations, were not detected in the sites surveyed.

Free-living nematodes are highly sensitive to changes in the soil conditions and are considered to be useful indicators of changes in soil health. Nematode extraction and population counts are relatively simple and quick, and do not require expensive equipment compared to other methods that might be used for indicating soil health.

Soil testing for plant parasitic nematodes is also 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.

Soil microbial activity

In addition to soil nematodes, soil microorganisms such as bacteria and fungi are very sensitive to changes in soil conditions. Therefore, their population densities are dynamic, but they may be able to deliver timely indications on the adverse or beneficial effects of soil management practices on soil health. These microbiological indicators are particularly useful in providing a better understanding of rapid changes in the soil ecosystem, by providing profiles on the soil organic matter, food-web and soil conditions. Other soil indicators mentioned previously, such as total carbon and structural properties, are the resulting effects of changes that occur over many years.

In general, higher levels of total microbial activities were recorded in the reference sites than in cropped sites, regardless of the different methodology used at the three laboratories. The differences in other microbiological indicators, such as total bacteria, total fungi, gram +ve bacteria, gram -ve bacteria and mycorrhizal fungi, followed a similar pattern to the total microbial activities, where all carrot sites had lower values than reference sites.

The significant correlation of many of these microbial indicators with total nitrogen, total carbon, and labile carbon C1 demonstrate the interconnections between all these values. These relationships also support the widely held view among many soil scientists of the sensitivity of microbial indicators in detecting changes in the quality and quantity of soil organic matter.

Unfortunately, the impact of changes to these microbiological indicators on crop productivity cannot be properly assessed in this survey study. The greatest differences in the microbiological communities occurred between reference and cropped sites, but no carrot crops were produced in the reference sites to enable comparative studies. A comparative study of these values would also be best provided in field trials involving replicated plots with different management practices, but on the same soil type, previous history and localized conditions.

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.

Organic matter

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.

Soil health

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

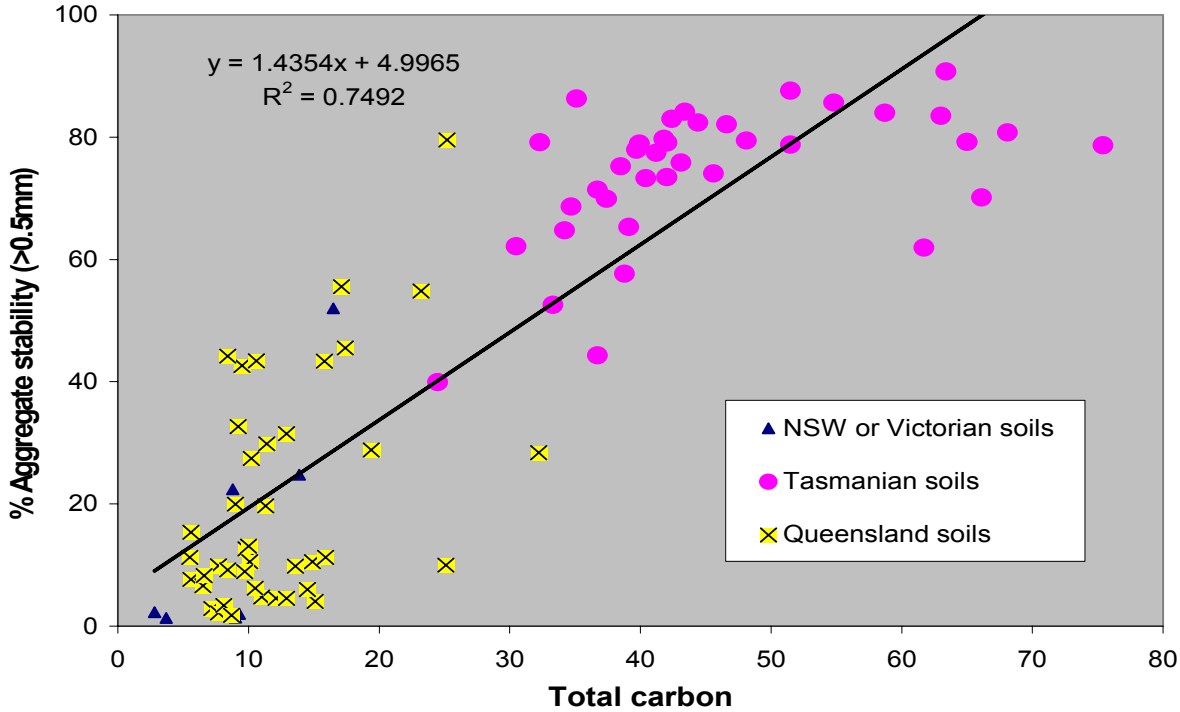
Aggregate stability & soil carbon

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.

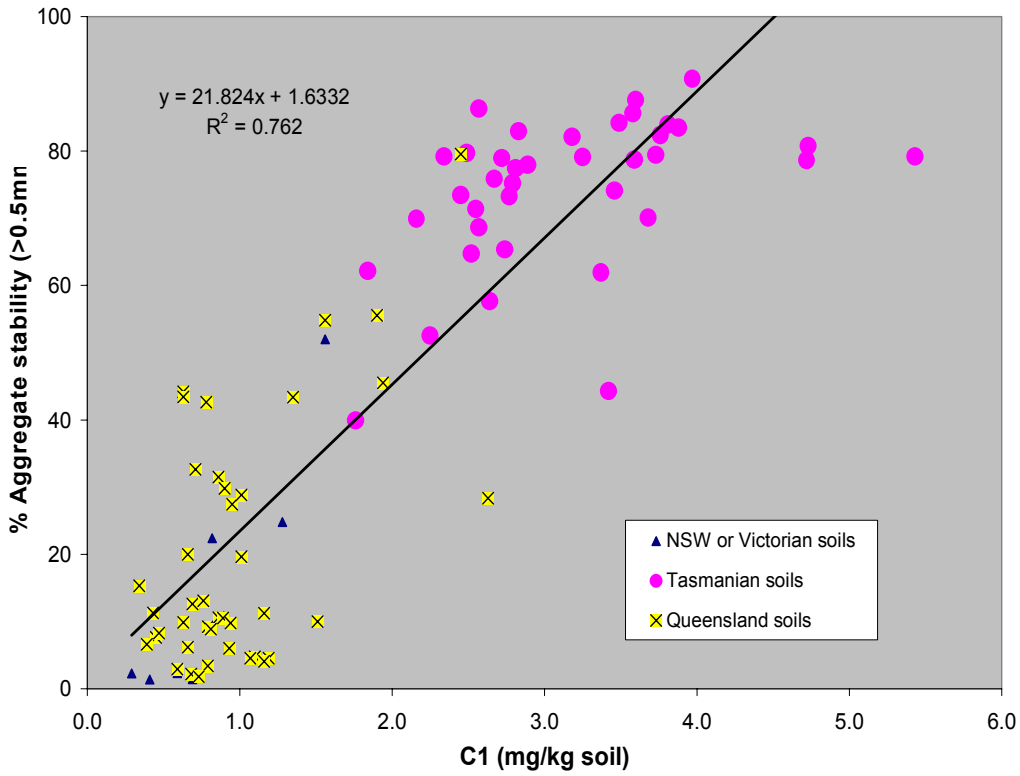


Some cropped sites in Tasmania showed similar or slightly higher values in both measurements compared to reference sites. This indicates that with good farm management practices, even with intensive land use for vegetable production, soil integrity and soil health can be sustainable. Unfortunately, in 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.

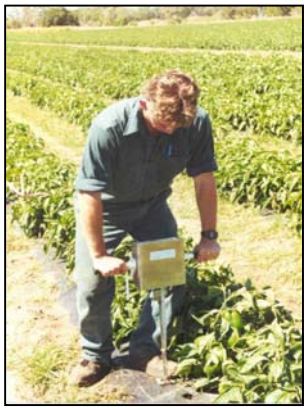


<u>Soil structure score & penetration resistance</u>

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

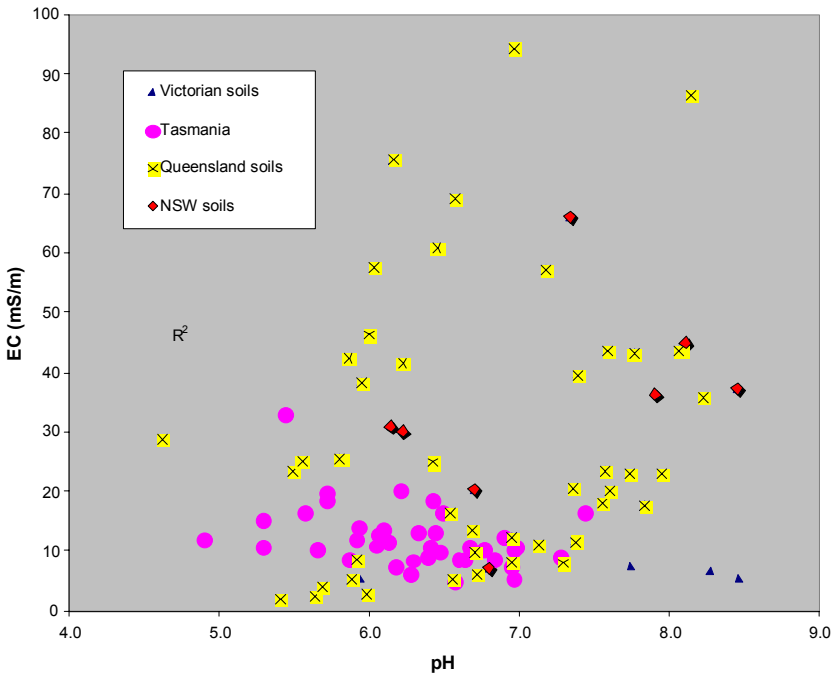
Soil EC and pH

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.

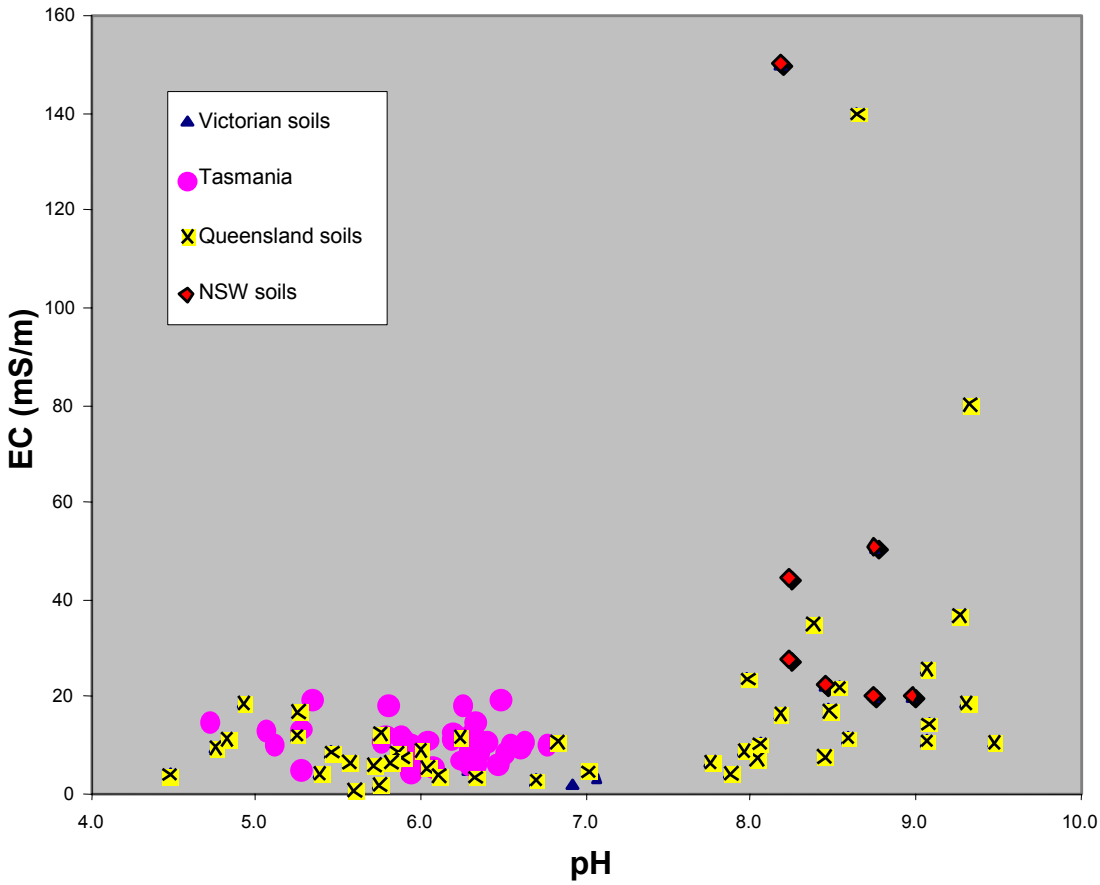


In general, most of the pH (1:5 water) values are within acceptable limits (pH range of 5.5 to 7.5) for plant growth and microbial activity. There are exceptions, where a pH of less than 5.5 was recorded in 11% of the sites in Tasmania, and a pH of greater than 7.5 in 24% sites in

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.

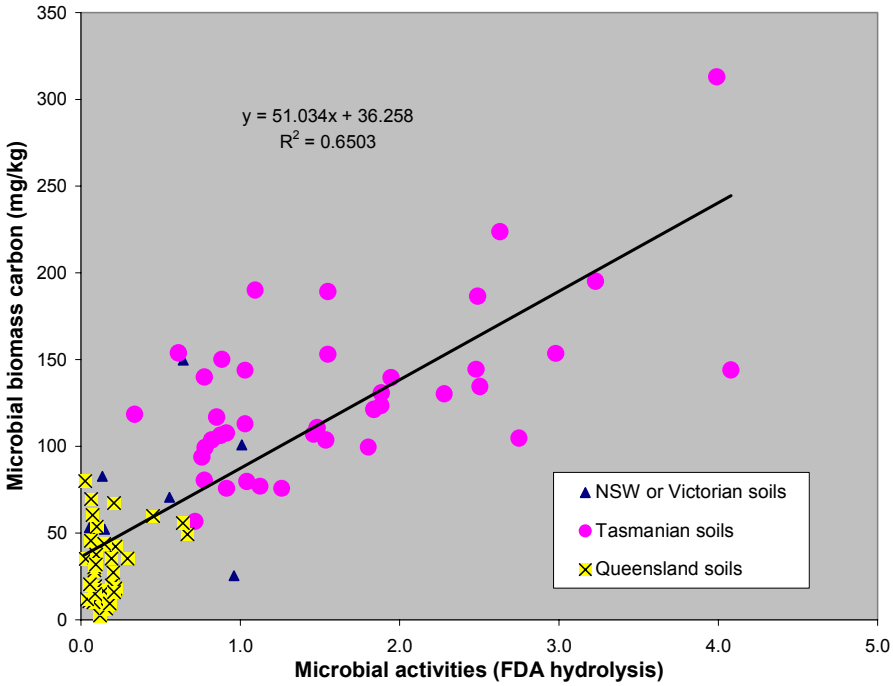
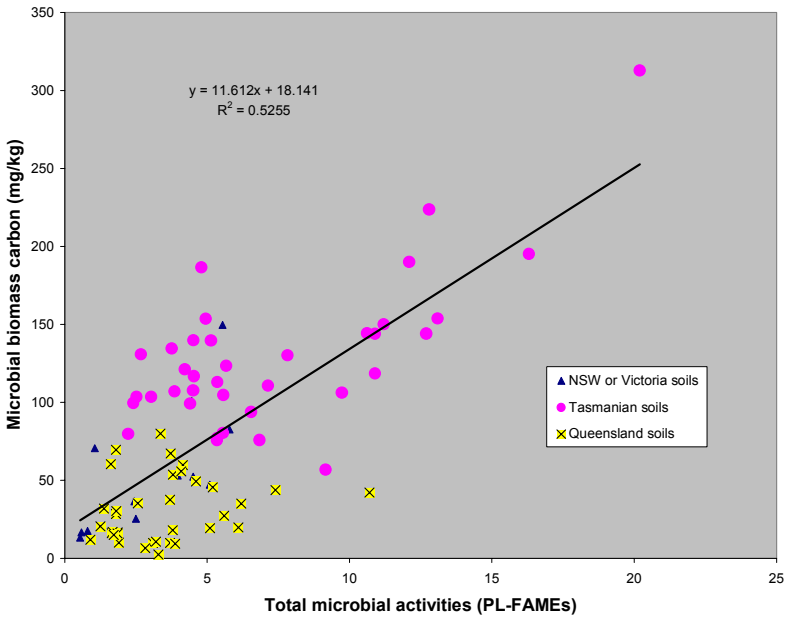


Figure 5.6: The relationship between microbial biomass carbon and total microbial activities (PL-FAMEs) of soils from cropped and reference sites in Queensland, Tasmania, NSW and Victoria.



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.***

6.2 Industry Forums

Industry forums were held in Queensland and Tasmania to share results with growers and other interested stakeholders and interpret their meaning in an interactive way to maximize the learning opportunity for all involved.

Queensland forums

Two industry forums were held at Bowen and Bundaberg by Jason Olsen and Larissa Bilton (facilitator) in May 2002 to present and discuss results of soils from Queensland. The basic agenda used for the Queensland forums was:

- What makes a soil healthy? – presentation by Jason Olsen
- Small group discussion – How healthy are our soils? (development of historical profiles)
- Presentation of the survey results – Jason Olsen
- Group discussions
    - What can horticulture learn from these results?
    - What should be the industry priorities regarding soil health?
    - Reflection: What have I learnt from this?

At the conclusion of each forum, feedback was requested to help improve the process but also to help participants articulate what they might do differently as a result of attending the forum. The details of the feedbacks from each forum are presented in Appendix 6.

Tasmanian forum

An industry forum was held in Devonport by Hoong Pung, Bill Cotching and Doris Blaesing (facilitator of discussion) on 24th March 2003 to present and discuss results of soils from Tasmania. A total of 29 people (excluding organisers), consisting mostly of growers, farm consultants, and representatives from processing companies, attended the forum.

The agenda covered in the forum under each speaker was:

Hoong Pung

- What factors affect carrot yield and quality?
- How soil factors affect carrot quality?
- What is soil health, and what are the key indicators of soil health?
- The status of soil health in Tasmania

Bill Cotching

- Soil structure assessments
- Why does soil structure affect crop yield?
- Cost of degraded Ferrosol soil structure
- Management of degraded soil

Doris Blaesing

- Soil health – what is it for agriculture?
- What is soil quality in agriculture?
- Composition of a good soil compared to a poor soil
- Why soil compaction is a problem?
- The role of organic matter, soil carbon and microflora

Discussion (facilitated by Doris)

- Can we monitor soil quality?
- What is the way forward?

Feedback from industry in discussions

- Extension of research findings to more growers through small growers group vital
- Practical information and advice on what to do is needed by growers
- Ideal next step is to produce a check list on soil (e.g. carbon, visual structure score, history)
    - To identify where degradation is a concern, and what to do with it
    - Need to do this under an extension type project?
    - But how useful is a generic checklist for soil structure?

- Soil preparation offers greater choice for growers
    - It can be managed, unlike harvesting, e.g. under wet conditions, etc.
    - This could mean that planting in spring and harvesting in winter could be more harmful to soil than planting in winter and harvesting in spring.
    - Harvesting operations with heavy machinery create big potential for soil damage.
    - Soil compaction by heavy machinery in saturated soil can be irreversible or can take many years to recover.
    - Good soil management can turn around low productive land to highly productive land in just one year.
        - This is shown by the biggest change in crop productivity in the same paddock noted with a change in farm ownership.

- With move to bigger paddocks incorporating several smaller paddocks – how do you manage different soil quality?
- Changes in soil under different management practices require a long term monitoring study to identify sustainable practices.

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Appendix 1 – Grower's questionnnaire

Questionnaire used for the capsicum and carrot sites in Qld, Tas, NSW and Vic. Growers were asked questions that helped quantify the management procedures they used and their perceived status of the soil and crop health at the sample site (Q 1-25). Researchers familiar with capsicum assessed the status of the health of plants at each site at the time of sampling (Q 26-35).

Grower's name & location: ……..
Block identification: ……..
Crop & cultivar: ……..

CROPPING HISTORY

1 What crops (including cover or green manure crops) have you grown in the last 5 years in the block we surveyed on your farm?

Year	Crops(s) grown *Please list both vegetable and cover crops*	Fumigant applied and rate
2000		
1999		
1998		
1997		
1996		
1995		

2. How would you describe your cropping history *(Please tick one)* ?

☐ Intensive vegetable cropping
☐ Intermediate cropping with breaks of pasture and other non-vegetable crops
☐ Long pasture breaks between crops

3. Over the last 5 years, has the yield of your capsicum/ carrot crops *(Please tick one)*

☐ Increased
☐ Decreased
☐ Stayed the same

CROPPING PRACTICE

4 If you use a green manure crop, what effect do you expect it to have on the soil and subsequent crops?

……...

5 Surface cover (Please tick one)

- ☐ Soil surface is clean, bare, residue removed or buried following the last crop
- ☐ Surface has little residue, mostly buried
- ☐ Surface is trashy, lots of mulch left on top or crop used

6 Which of those listed below have you increased the use of over the last 5 years?

- ☐ Irrigation
- ☐ Fertiliser
- ☐ Herbicides
- ☐ Soil fumigation
- ☐ Fungicides
- ☐ Insecticides
- ☐ Nematicides
- ☐ Other (please specify) ……..

7 List the fertilisers and pesticides applied to the capsicum/ carrot crop we surveyed (please include rates and timing).

Soil fumigant: ……..

Fertiliser: …….

Herbicide: ……

Fungicide: ……

Insecticide: ……...

Nematicide: ……...

Were the seeds chemically treated? YES / NO ; if yes state the treatment applied

……...

8 Do you regularly use any form of irrigation scheduling on your farm?

YES / NO ; if yes, what type?……..

9 Over the crop's life, how much irrigation water do you estimate was applied to the crop we surveyed? (ML/ ha).

…….

CULTIVATION

10 Do you deep cultivate? **YES / NO**

11 If NO, why not?

……

12 If YES, what do you consider to be the benefits of deep cultivating?

……

13 Seedbed preparation (carrot)/ Preplant soil preparation (capsicum) in crop we surveyed

Date preparation commenced & finished: Start date: ……. Finish date: ……...		**Seeding / Planting Date:** ……	
Cultivation order and number of operations			
Operation	**Date**	**Number of passes 1,2,3 etc and soil moisture during each pass (dry, moist, wet)**	**Depth of tillage (cm)**
Plough			
Agrow Plow			
Rotary hoe			
Rottera			
Other implements used			
Discs			
Harrows			
'S' tyne			
Any further preparation comments	e.g. rating quality of seed bed/ soil preparation (very poor, poor, moderate, good, very good), etc.		

FARMER ASSESSMENT OF SOIL HEALTH

Questions refer primarily to the plough layer of the block we sampled on your farm

14 Over the past five years, has soil structure deteriorated on the block we sampled? *(Please tick any number of indicators which may apply)*

- ☐ increasing difficulty in ploughing
- ☐ large dense clods being brought to the surface
- ☐ 'melting down' of a seedbed under rainfall/irrigation
- ☐ increased incidence of surface sealing or waterlogging
- ☐ soil staying wetter longer after irrigation/rainfall
- ☐ poorer rainfall/irrigation infiltration
- ☐ crops showing water stress earlier after irrigation or rainfall

(For the following questions, please tick one box per question)

15 Erosion

- ☐ severe erosion, considerable topsoil moved, gullies formed
- ☐ moderate erosion, signs of sheet and rill erosion, some topsoil blows
- ☐ little erosion evident, topsoil resists erosion by water or wind

16 Tillage ease

- ☐ Plow scours hard, soil never works down
- ☐ Soil grabs plow, difficult to work, needs extra passes
- ☐ Plow field in higher gear, soil flows & falls apart, mellow

17 Cloddiness

- ☐ Soil is cloddy with big chunks, or dusty and powdery
- ☐ Soil is lumpy or does not hold together
- ☐ Soil is crumbly, granular

18 Surface crust

- ☐ Soil surface is hard, cracked when dry, compacted
- ☐ Surface is smooth with few holes, thin crust
- ☐ Surface does not crust, porous, digs easily with hand

19 To what extent is soil structure decline affecting the viability of your farming business:-

- ☐ Extreme
- ☐ Moderate
- ☐ Insignificant

20 Infiltration

- ☐ Water does not soak in, sits on top or runs off
- ☐ Water soaks in slowly, some run-off or puddling after a heavy rain
- ☐ Water soaks right in, soil is spongy, no ponding

21 Decomposition

- ☐ Residues and manures do not break down in soil
- ☐ Slow rotting of residues and manures (e.g. 2-3 months?)
- ☐ Rapid rotting of residue and manures (e.g. 1-2 months?)

22 Smell

- ☐ Soil has a sour, putrid or chemical smell
- ☐ Soil has no odor or a mineral smell
- ☐ Soil has an earthy, sweet, fresh smell

OVERALL CROP YIELD FROM THE BLOCK WE SAMPLED

23 How many 8 kg cartons of marketable capsicum fruit do you estimate you harvested from the block we surveyed?

- ☐ Less than 3,000 cartons per ha (less than 1,200 cartons per acre)
- ☐ 3,000 to 4,000 cartons per ha (1,200 to 1,600 cartons per acre)
- ☐ 4,000 to 5,000 cartons per ha (1,600 to 2,000 cartons per acre)
- ☐ Greater than 5,000 cartons per ha (greater than 2,000 cartons per acre)

OR

Carrot gross yield

- ☐ tonne per ha (20 to 30)
- ☐ tonne per ha (30 to 50)
- ☐ tonne per ha (greater than 50)

24 Quality of produce

CAPSICUM

- ☐ less than 60% pack-out rate
- ☐ 60-70% pack-out rate
- ☐ 70-80% pack-out rate
- ☐ 80% or greater pack-out rate

What is the target pack-out rate for this variety (%)? ……..

OR

CARROT

- ☐ less than 60% pack-out rate
- ☐ 60-70% pack-out rate
- ☐ 70% or greater pack-out rate

What is the target pack-out rate for this variety (%)? ……..

25 Main cause of reduced or increased pack-out

E.g. problems associated with seed or transplant quality, variety, weather, management changes, disease, insect pests, shape, size, or quality of fruit.

……..

……..

……..

PLANTS (to be completed by researcher during the survey)

Questions relate to the crop plants at the site that was sampled

(Rating out of 4. Please circle the answer which best describes the crop).

26 Crop appearance

0 Overall crop is poor, stunted, in an uneven stand
1
2 Overall crop is small, in an uneven stand
3
4 Crop is large, tall, in an even stand

27 Nutrient deficiency

0 Crop shows signs of severe deficiencies (necrosis, blight, streaky, chlorosis, discoloured, dry leaves)
1
2 Crop falls off or discolours as season progresses
3
4 Crop has what it needs, shows little signs of deficiencies

28 Plant density

CAPSICUM
0 Plant density is low, with widespread death of individual plants in the block
1
2 Plant density is moderate; moderate death of individual plants in the block
3
4 Good plant density, virtually no death of transplanted individuals in block

OR
CARROTS
0 Plant density is low, hard for crop to come out of ground
1
2 Plant density is uneven; seed must be planted deeper
3
4 Good plant density

29 Growth rate (use knowledge of cultivar to assess growth rate, if necessary)

0 Crop slow to get started, never seems to mature
1
2 Uneven growth, late to mature
3
4 Rapid, even growth, matures on time

30 Roots

0 Plant roots appear unhealthy (brown, diseased, spotted, knobbly), misshapen
1
2 Plant roots are shallow, at hard angles, development limited, few fine roots
3
4 Plant roots are well-shaped, deep, fully developed

31 Foliage

0 Leaves are yellow, discoloured, few in number
1
2 Leaves are small, narrow, light green
3
4 Leaves are full, lush, dark green

32 Resists drought

0 Plants dry out quickly, never completely recover
1
2 Plants suffer in dry weather, slow to recover
3
4 Plants withstand dry weather, fast to recover

33 Resists pests and disease

0 Plants damaged severely by diseases and insects
1
2 Plants stressed by disease and insects
3
4 Plants tolerate pests and disease well

34 Weed pressure

0 Weeds not controlled (weed density higher than crop density)
1
2 Acceptable weed control (moderate weed pressure)
3
4 Complete weed control

35 List major type of weeds in the sample area

……

……

Appendix 2 – Site details

Details of sites surveyed in Queensland

For confidentiality, the names of growers participating in the survey have not been included in this table.

Site code	Location: Australian Geodetic Datum 84	Soil Order	Sample date	Crop stage	Notes & History of Site
Q1 Block 49	617954 mE 7776126 mN	BLACK VERTOSOL	29 Aug 2000	Green mature Double row	New plastic, good weed control. Samples taken on 29 Aug 00 at 13 wk after transplant on 30 May 00. 2000 Merlin capsicum (sodium metham) 1999 Capsicum 1998 Capsicum
Q1-1			29 Aug 2000		Adjacent to Block 49. Pasture.
Q2 Block 18	618720 mE 7775010 mN	BLACK VERTOSOL	29 Aug 2000	Green mature Double row	New plastic. 6th crop of Merlin. Plants in Block 18 planted 1 wk later than Block 49 (transplanted 6 June 00). 2000 Merlin capsicum (sodium metham) 1999 Fallow, soil stripped
Q3 Block 24	619195 mE 7775168 mN	BLACK VERTOSOL	29 Aug 2000	Green mature Double row	New plastic. Plants in Block 24 planted 1 wk later than Block 18. 2000 Merlin (sodium metham) 1999 Melons 1998 Fallow
Q4 Block 26	619448 mE 7775310 mN	BLACK VERTOSOL	30 Aug 2000	Green mature Single row	No plastic, beds formed, irrigated, metham sodium 200 L/ha through trickle, SpraySeed day before planting. Plants in Block 26 planted 1 wk later than Block 24. 2000 Merlin (sodium metham) 1999 Tomatoes 1998 Fallow
Q4-1			30 Aug 2000		Adjacent to Block 26. Scrub
Q5 C14	614637 mE 7776280 mN	ALLUVIAL SOIL	30 Aug 2000	Green mature Double row	New plastic. Some plants looked like water-logging a problem as they were slightly stunted. Hard pan around 20-30cm. Nut grass present. Alluvial soil 2000 Merlin (metham 800 L/ha) 1999 Watermelon 1998 Watermelon 1997 Sudax 1996 Sudax
Q6 C16	614817 mE 7776342 mN	ALLUVIAL SOIL	30 Aug 2000	Green mature Double row	New plastic. 2000 Merlin (metham 800 L/ha) 1999 Pumpkin 1998 Grass
Q7 Planting 13 of Home Block 2 (low end)	624118 mE 7786907 mN	BLACK DERMOSOL	30 Aug 2000	Green mature Double row	New plastic. Low end of block seemed to have reduced growth to rest of block. 2000 Merlin (metham 130 L/ha) 1999 Merlin (metham 130 L/ha) then forage 1998 Merlin (metham 130 L/ha) then forage 1997 Merlin (metham 130 L/ha) then forage 1996 Cover crop, ground spelled
Q8 Planting 13 Home Block 2 (middle end)	624225 mE 7787152 mN	BLACK DERMOSOL	30 Aug 2000	Green mature Double row	New plastic. Middle end of block appeared to have better growth than the low end
Q9 Jensen's block	6239535 mE 7787695 mN	BLACK DERMOSOL	31 Aug 2000	Fruit set Double row	New plastic. Lots of nut grass. Easy penetration with the penetrometer. 2000 Merlin (metham 300 L/ha) 1999 Merlin (metham 200 L/ha) 1998 Merlin (metham 200 L/ha) then forage 1997 Rockmelon (no metham) then forage
Q9-1			31 Aug 2000		Adjacent to Jensen's block. Pasture
Q10 Block E, close to mangoes	626479 mE 7788152 mN	BLACK DERMOSOL	31 Aug 2000	Green mature Double row	New black plastic. 2000 Merlin (no metham) 1999 Merlin (no metham)
Q11 JTC5	572437 mE 7799943 mN	BROWN DERMOSOL	31 Aug 2000	Green mature Double row	New black plastic. Had applied gypsum. Had grown capsicum for about 10 years without metham. 2000 Merlin (no metham) 1999 Merlin (no metham) 1998 Fallow Previous 10 years- Capsicums
Q11-1			31 Aug 2000		Adjacent to JTC5. Pasture
Q12	563147 mE	BLACK	1 Sep 2000	Fruit set	Double rows of capsicum on old white plastic

Site code	Location: Australian Geodetic Datum 84	Soil Order	Sample date	Crop stage	Notes & History of Site
Block 17	780607 mN	VERTOSOL		Double row	previously planted to honey dew melons. 2000 Honey dew => Merlin (metham) on same white plastic 1999 Rockmelons (no Vapam) 1998 Melons => Merlin
Q13 Back Block H Short		GREY SODOSOL	1 Sep 2000	Early fruit set Double row	Double row capsicum in black plastic after melon (old melon stalks in the ground). 2000 Honey dew => Merlin (metham) on same black plastic 1999 Melons (no Vapam)
Q14 Block 11	435196 mE 7234089 mN	YELLOW DERMOSOL	20 Mar 2001	Early fruit fill Single row	cv. Matrix. Trellises used. No MBr or metham sodium used. Planted one week later than Block 10.
Q14-1	435224 mE 7234059 mN	YELLOW DERMOSOL			Scrub southern side of Block 11. Scrub
Q15 Block 10	435392 mE 7234213 mN	BROWN DERMOSOL	20 Mar 2001	Late fruit fill Single row	cv. Matrix. Trellises used. No MBr or metham sodium used. No MBr applied.
Q16 Block 12 South sandy end	435582 mE 7235537 mN	GREY SODOSOL	21 Mar 2001	Fruit fill Single row	cv. Matrix Sandy end of Block 12. Trellises used. No MBr or metham sodium used.
Q17 Block 12 North clay end	435648 mE 7239444 mN	GREY CHROMOSOL	21 Mar 2001	Fruit fill Single row	cv. Matrix Clay end of Block 12. Trellises used. No MBr or metham sodium used.
Q17-1 Reference site	435693 mE 7235845 mN	GREY SODOSOL			Adjacent to clay end of Block 12
Q18 Block 1	440670 mE 7251709 mN	PODOSOL	21 Mar 2001	Late fruit fill Double row	cv. Matrix. About 5% of plants infected with TSWV. Staggered plants. 2001 Capsicum cv. Matrix (First harvest around 28 March 2001)
Q19 Bongiolettis Rd	423453 mE 7259006 mN	YELLOW DERMOSOL	22 Mar 2001	Early fruit fill Single row	cv. Besser. Not well drained (water lying in inter-rows). Off Bongiolettis Road.White plastic, single trickle. No Metham
Q20 'U5' Eubal Farm	428739 mE 7246854 mN	REDOXIC HYDROSOL	26 Mar 2001	Fruit fill Double row	Block with southerly aspect. Cv Bombardier (Fairbank seeds).. No MBr or metham sodium used now for a couple of years.
Q21 Cv. Bombardier	423271 mE 7246301 mN	BROWN SODOSOL	26 Mar 2001	Very late fruit fill	Reused same plastic, melon-capsicum rotation. Methyl bromide used before melons in Spring. Second bay past H/works filter. Double crop black plastic melons spring 2000 with methyl bromide. Planted capsicum cv. Bombardier into same plastic (sprayed white).
Q22 Block 1	440409 mE 7240850 mN	RED KANDOSOL	27 Mar 2001	Fruit fill Double row	cv. Target. No MBr this year. No CO3 put on at planting. White plastic on this block, but black plastic on adjacent Q33. No methyl bromide this year.
Q23 Corner Wolfenden and Dr Mays	439905 mE 7240601 mN	RED KANDOSOL	27 Mar 2001	Fruit fill	First harvest due first week in May. Cv. Helix (confidential). Filter press and humic acid (lignite) added to soil each yr. Humic acid (12%) through the trickle. MBr used before each crop. Has been planted twice a year with capsicum since 1995 by Lou and since 1993 by Laurie Fritz. Lou uses filter press and Humic Acid every year on the block. Methyl bromide used before each block.
Q24 Block 21 Home farm	440700 mE 7238298 mN	YELLOW DERMOSOL	27 Mar 2001	Early fruit fill	cv. Merlin. Plants trellised. Rows running NE to SW. Metham sodium was used this year, but not in previous years.
Q24-1 (Ref to Q24)	440699 mE 7238605 mN	YELLOW DERMOSOL			Virgin forest next to Q24.
Q25 Block 27 Nedwich Rd	440078 mE 7239525 mN	YELLOW DERMOSOL	27 Mar 2001	Early fruit fill	cv. Helix Lots of metham sodium used on this block, for this crop and for previous crops.
Q26 Block 5A	439667 mE 7243553 mN	RED KANDOSOL	27 Mar 2001	Fruit fill Double row	cv. Target. Black plastic painted white. Single trickle. No fumigation employed at all on block.

Site code	Location: Australian Geodetic Datum 84	Soil Order	Sample date	Crop stage	Notes & History of Site
Q27 Block 3	440568 mE 7236482 mN	YELLOW KANDOSOL	29 Mar 2001	Fruit fill	Methyl bromide applied. 2001 Capsicum cv. Helix (early bud development at 14/3/01)
Q28 Block 1	447489 mE 7244600 mN	RED KANDOSOL	29 Mar 2001	Green mature Double row	cv. Toledo. No filter press. MBr applied at half rate of 50 kg/acre. Lots of sunburn damage due to overuse of N and lodging bushes. White plastic. MBr at half rate.
Q29 Block 4	447406 mE 7244323 mN	RED KANDOSOL	29 Mar 2001	Fruit fill Double row	cv. Toledo. Filter press and humic acid applied. MBr applied at half rate of 50 kg/acre. Sap at fruit fill was 4,520 mg NO_3/L vs around 1,500 at the CNC at fruit set.White plastic. MBr at half rate. Sorghum used in inter-rows to reduce sand blast.
Q30 (+ Metham – Cobb's block)	428856 mE 7245962 mN	RED CHROMOSOL	Late April 2001	Planted around 24/3/01 Single row	Bowen growers apply metham sodium at 200 L/ 5 acres. This block had metham at 150 L/5 acres. The 5 bays closest to Gorlicks Rd. White plastic. Single trickle. Cv. Target grown in Cobb's block with metham sodium at 150 L/ 5 acres.
Q31 (- Metham Cobb's block)	428828 mE 7245870 mN	RED CHROMOSOL	Late April 2001	Planted around 24/3/01 Double row Early fruit set	Adjacent to Q30, but the 8 bays closest to the Q31-1 reference site. Rows E to W. White plastic. Single trickle. Cv. Target grown in Cobb's block without metham sodium and adjacent to a block with metham sodium.
Q31-1 Next to Q31	428857 mE 7245808 mN	PODOSOL			Pasture next to Q31 at Cobb's Block.
Q32 Cv. Target (third bay from cane)	424056 mE 7246367 mN	BROWN SODOSOL	Around late April 2001.	Planted around 24 Mar Early fruit set	Reused same plastic, melon-capsicum rotation. Methyl bromide used before melons in Spring. Double cropping system. Black plastic melons spring 2000 with methyl bromide. Planted capsicum cv. Target into same plastic (sprayed white).
Q33 (MBr before planting)	440493 mE 7240850 mN	Bleached-orthic TENOSOL	Late April 2001	Planted around 31 March 01 Early fruit set	Double row. Cv. Target. Grown on black plastic. Methyl bromide used on this block. No MBr used on the adjacent Q22. Sampled on 27 Mar 01
Q34	422931 mE 6948887 mN	BLACK DERMOSOL	15 Nov 2001	Late fruit set Triple row	Cv.Aries. Grown on black plastic, double trickle. 1.8m beds & 500mm plant spacings + 1998 Caps & cauliflower 1999 Caps & lettuce 2000 Carrots 2001 Caps & cauliflower
Q35	433106 mE 6951937 mN	BROWN VERTOSOL	15 Nov 2001	Late fruit set Triple row	Cv.Aries. Grown on black plastic, double trickle. 1.8m beds & 500mm plant spacings 1998 Caps & lettuce 1999 Carrots 2000 Caps & cauliflower 2001 Caps & lettuce
Q36	437000 mE 6952600 mN	BLACK VERTOSOL	16 Nov 2001	Late fruit set Double row	cv. Aries.White plastic, single trickle. 1.5m beds & 300mm plant spacings. 1996 Lucerne 1997 Lucerne 1998 Lucerne 1999 Lettuce & caps 2000 Lettuce & caps 2001 Lettuce & caps

Carrot growers surveyed in South Australia and Victoria with questionnaire only

Location	Cropping History	Is soil fumigation used? (Type)	Increased practices
SOUTH AUSTRALIA			
Virginia	Intermediate	No	Fertiliser, Fungicides
Parilla	Intermediate	Yes (Nemacur)	Fertiliser, Fungicides
Uraidla	Intermediate	No	Irrigation, Fertiliser, Herbicides, Fungicides, Insecticides
Nuriootpa	Intermediate	Yes (Metham sodium)	Soil fumigation
Virginia	Intensive	Yes (Metham sodium)	Irrigation, Fungicides
Virginia	Intensive	Yes (Metham sodium)	Irrigation, Soil fumigation, Fungicides
Angle vale	Intensive	Yes (Metham sodium)	Soil fumigation
Bow Hill	Intensive	Yes (Metham sodium)	Irrigation, Fungicides
VICTORIA			
Cranbourne	Intensive	No	Insecticides and fungicides have decreased, but recorded increased soilborne diseases
Yarrawonga	Intensive	Yes (Nemacur)	Insecticides
Silvan	Intensive	No	Irrigation
Somerville	Intensive	No	Irrigation, Insecticide
Baxter	Intermediate	No	Irrigation
Devon Meadows	Intensive	No	Herbicides, Fungicides, Irrigation
Pearcedale	Intermediate	No	N/a
Fiveways	Intensive	No	Irrigation, Fertiliser, Fungicides

Appendix 3 – Data analysis

MATRIX OF PAIRWISE SIMPLE CORRELATION

Matrix of all possible pairwise simple correlation coefficients for information collected from the crop sites in Queensland.

An explanation of the codes used in the matrix is as follows:
%BFN = % bacterial feeding nematodes of total free living nematodes;
%FFN = % fungal feeding nematodes of total free living nematodes;
AvWtMk = Average weight of a marketable fruit;
BFN = number of bacterial feeding nematodes per 200 mL soil;
C1 = g carbon fraction 1 per kg soil;
C1_TotC = percent C1 of total carbon;
C3 = g carbon fraction 3 per kg soil;
C_N = total soil carbon divided by total soil nitrogen;
Ca = kg calcium applied per ha;
Clodness = rating of cloddiness (1 cloddy – 3 crumbly);
CropApp = rating of crop appearance (1 poor – 4 great);
DmaxVal = depth of the maximum penetrometer value (mm);
EC0_15 = electrical conductivity (dS/m) in the surface 15 cm of soil;
EC45-60 = electrical conductivity (dS/m) in the subsoil (45-60 cm);
FDA = total microbial activity as measured by µg fluorescine diacetate hydrolised/g/min;
FFN = number of fungal feeding nematodes per 200 mL soil;
FFtoBF = ratio of fungal feeding to bacterial feeding nematodes per 200 mL soil;
FLN_Para = ratio of free living nematodes to parasitic nematodes per 200 mL soil;
FluoPseu = $\log_{10}$ colony forming units of fluorescent pseudomonads per g dry soil;
Foliage = rating of foliage of the crop (1 poor – 4 great);
FrtWtRa = percent marketable fruit of total fruit by weight;
Fun_Bac = ratio of fungi to bacteria (µg/g soil) as determined by phospholipid fatty acid methyl esters (PL-FAMEs);
Fungi = fungi (µg/g soil) as determined by PL-FAMEs;
Gneg = gram negative bacteria (µg/g soil) as determined by PL-FAMEs;
Gpos = gram positive bacteria (µg/g soil) as determined by PL-FAMEs;
K = kg potassium applied per ha;
MBC = microbial biomass carbon (mg C/kg soil);
Mg = kg magnesium applied per ha;
ML_ha = estimated ML irrigation water used for the crop;
N = kg nitrogen applied per ha;
NoFalls = number of fallows in the last 5 years;
NoFums = number of soil fumigations in the last 5 years;
NoGMs = number of green manure crops grown in the last 5 years;
NoSolC = number of solanaceous crops grown in the last 5 years;
NoWdSp = number of weed species found at the site;
Omniv = number of omnivorous nematodes per 200 mL soil;
P = kg phosphorus applied per ha;
pH0-15 = pH in the surface 15 cm of soil;
pH45-60 = pH in the subsoil (45-60 cm);
PLFAME = total phospholipid fatty acid methyl esters ((µg/g soil);
Roots = rating of root appearance of the crop (0 poor – 4 great);
S = kg sulfur applied per ha;
SurfCrt = rating of surface crusting (1 hard-setting – 3 digs easily);
TotBac = total bacteria (µg/g soil) as determined by PL-FAMEs;
TotC = g total carbon/kg soil;
Tot FLN = number of free living nematodes per 200 mL soil;
TotN = g total nitrogen/kg soil;
TotPara = number of free living nematodes per 200 mL soil;
TotPass = total number of passes with cultivation equipment for that crop;
TotRot = total number of passes with a rotary hoe or power harrows for that crop;
VAM = total mycorrhizae (µg/g soil) as determined by PL-FAMEs;
WeedPr = rating of weed pressure (1 poor control – 4 great control);
WtMktFr = weight of marketable fruit (t/ha);
Yld5Yrs = grower rating of how yield has changed over the last 5 years (1 increased, 2 decreased, 3 same).

Matrix of all possible pairwise simple correlation coefficients for information collected from the capsicum crop sites in Queensland.

Although there were 36 cases (sites), information from 6 of these cases was incomplete for all measurements taken. Since the analytical procedure required complete cases, there were 30 cases included in the final procedure. Therefore, there were 28 degrees of freedom (allowing 1df for each of intercept and slope).

The necessary value of r (correlation coefficient) for significance at *P*=0.05 for n=30 (28 degrees of freedom) is 0.36. These values are presented in bold type.

Positive values imply a positive relationship, whereas negative values indicate a negative relationship.

	%BFN	%FFN	AvWt Mk	BFN	C1	C1_Tot C	C3	C_N	Ca	Clodness	Crop App
%BFN	1.00										
%FFN	**-0.99**	1.00									
AvWtMk	-0.09	0.14	1.00								
BFN	0.13	-0.19	-0.27	1.00							
C1	-0.25	0.23	-0.03	**0.47**	1.00						
C1_TotC	0.06	-0.06	-0.19	0.32	0.07	1.00					
C3	-0.14	0.13	0.02	0.33	**0.91**	-0.19	1.00				
C_N	-0.31	0.32	0.05	-0.09	**0.53**	**-0.38**	**0.66**	1.00			
Ca	**-0.41**	**0.47**	0.29	-0.30	-0.07	-0.15	0.02	0.17	1.00		
Clodness	0.30	-0.32	0.04	-0.04	0.19	0.19	0.23	0.17	**-0.51**	1.00	
CropApp	-0.18	0.20	**0.46**	0.12	0.05	0.10	-0.01	-0.16	0.11	-0.06	1.00
DMaxVal	-0.28	0.29	0.07	-0.13	0.03	**-0.44**	0.07	**0.36**	-0.17	-0.10	0.24
EC0_15	**-0.39**	**0.37**	0.29	0.34	0.29	-0.16	0.18	0.15	0.33	**-0.37**	0.02
EC45_60	-0.03	-0.01	-0.06	0.35	-0.09	0.11	-0.22	**-0.40**	-0.20	**-0.38**	0.05
FDA	-0.19	0.21	0.08	-0.07	**0.59**	-0.35	**0.67**	**0.66**	0.08	0.01	-0.34
FFN	**-0.67**	**0.59**	-0.13	**0.47**	**0.37**	0.01	0.21	0.16	-0.04	-0.22	0.18
FFtoBF	**-0.99**	**0.97**	0.08	-0.03	0.27	-0.05	0.15	0.28	**0.41**	-0.35	0.20
FLN_Para	-0.32	0.25	-0.16	**0.75**	**0.36**	0.16	0.20	0.01	-0.13	-0.20	**0.41**
FluoPseu	0.04	-0.07	**-0.38**	**0.51**	0.02	**0.57**	-0.08	-0.24	-0.03	-0.06	0.09
Foliage	-0.02	0.03	**0.50**	0.21	-0.11	0.10	-0.15	-0.24	0.15	-0.08	**0.74**
FrtWtRa	0.12	-0.13	-0.13	-0.05	-0.25	0.23	**-0.41**	**-0.47**	-0.21	-0.08	-0.04
Fun_Bac	0.05	-0.07	**-0.39**	0.14	0.01	**0.54**	-0.10	-0.30	-0.32	0.20	-0.22
Fungi	0.12	-0.13	**-0.42**	**0.40**	0.31	**0.54**	0.17	-0.23	-0.24	0.13	-0.21
Gneg	0.08	-0.08	-0.20	**0.43**	**0.50**	0.34	**0.37**	0.01	-0.08	-0.04	-0.05
Gpos	0.06	-0.06	-0.27	**0.44**	**0.47**	**0.41**	0.31	-0.07	-0.08	-0.07	-0.08
K	0.17	-0.17	-0.03	0.03	-0.26	-0.14	-0.24	-0.25	0.25	-0.22	-0.13
MBC	-0.20	0.17	0.29	0.30	0.33	-0.09	0.24	-0.03	-0.06	-0.23	0.11
Mg	**-0.41**	**0.47**	0.33	-0.29	-0.07	-0.14	0.02	0.19	**0.99**	**-0.48**	0.12
ML_ha	**0.58**	**-0.57**	-0.19	-0.15	**-0.39**	0.10	**-0.43**	**-0.47**	-0.29	0.04	**-0.43**
N	0.05	0.01	0.11	-0.16	-0.31	0.11	**-0.39**	-0.28	**0.44**	**-0.54**	-0.08
NoFalls	0.13	-0.11	0.33	0.23	0.31	-0.05	0.32	0.34	-0.14	0.17	-0.08
NoFums	0.31	-0.34	-0.01	0.03	**-0.46**	-0.02	**-0.42**	**-0.46**	0.02	0.00	-0.07
NoGMs	0.18	-0.23	**-0.47**	0.02	0.01	-0.05	0.10	-0.06	-0.21	0.34	-0.23
NoSolC	-0.08	0.08	0.20	-0.21	-0.26	-0.13	-0.17	-0.24	-0.07	0.17	0.35
NoWdSp	-0.12	0.13	0.34	**-0.44**	-0.12	-0.34	0.01	0.09	0.06	0.08	0.03
Omniv	**-0.62**	**0.53**	-0.14	**0.45**	0.34	-0.02	0.19	0.14	-0.07	-0.21	0.14
P	-0.14	0.15	0.27	0.12	0.07	0.04	0.03	0.20	**0.44**	-0.11	-0.00
pH0_15	-0.33	0.35	0.23	-0.06	-0.24	0.33	-0.31	-0.02	0.08	-0.07	**0.39**
pH45_60	0.07	-0.09	**-0.39**	**0.41**	0.00	**0.51**	-0.24	**-0.46**	**-0.46**	-0.09	0.09
PLFAME	0.07	-0.06	-0.21	**0.40**	**0.47**	**0.38**	0.33	-0.03	-0.10	-0.05	-0.07
Roots	-0.03	0.02	-0.04	0.10	-0.09	-0.04	-0.13	**-0.41**	0.09	-0.25	0.31
S	-0.35	**0.39**	0.18	-0.23	-0.06	-0.11	0.02	0.14	**0.94**	**-0.40**	0.01
SurfCrt	0.24	-0.24	0.12	0.05	-0.06	0.07	-0.08	-0.21	-0.18	0.38	0.03
TotBac	0.06	-0.07	-0.25	**0.44**	**0.48**	**0.39**	0.33	-0.04	-0.08	-0.06	-0.07
TotC	-0.27	0.26	0.06	0.20	**0.86**	**-0.43**	**0.90**	**0.68**	-0.00	0.09	-0.05
TotFLN	-0.22	0.15	-0.25	**0.91**	**0.49**	0.22	0.32	0.01	-0.23	-0.13	0.17
TotN	0.03	-0.05	0.01	**0.42**	**0.65**	-0.13	**0.58**	-0.09	-0.18	-0.02	0.15
TotPara	0.17	-0.17	-0.23	-0.20	-0.20	**-0.38**	-0.07	0.14	-0.09	-0.22	**-0.50**
TotPass	-0.15	0.14	-0.35	**0.39**	0.30	**0.36**	-0.02	-0.33	-0.16	-0.32	-0.02
TotRot	0.06	-0.06	0.10	-0.25	-0.01	-0.27	0.15	0.20	-0.17	**0.37**	0.04
VAM	-0.02	0.02	-0.29	**0.48**	**0.37**	**0.50**	0.17	-0.13	-0.25	-0.04	0.00
WeedPr	0.05	-0.05	0.22	0.05	-0.23	0.10	-0.33	-0.15	0.02	-0.20	0.18
WtMktFr	-0.00	0.03	0.02	0.12	0.09	**0.40**	-0.16	**-0.37**	0.10	-0.11	0.09
Yld5Yrs	-0.13	0.14	-0.12	0.16	-0.23	-0.15	-0.32	-0.16	0.23	**-0.56**	-0.13

	DMaxVal	EC0_15	EC45_60	FDA	FFN	FFtoBF	FLN_Para	Fluo Pseu	Foliage	FrtWtRa
DMaxVal	1.00									
EC0_15	0.07	1.00								
EC45_60	-0.05	**0.37**	1.00							
FDA	0.22	0.19	-0.33	1.00						
FFN	0.26	**0.53**	0.26	0.05	1.00					
FFtoBF	0.27	**0.47**	0.07	0.17	**0.75**	1.00				
FLN_Para	0.14	**0.40**	0.31	-0.15	**0.78**	**0.42**	1.00			
FluoPseu	-0.25	0.04	**0.37**	-0.33	0.12	-0.02	0.31	1.00		
Foliage	0.03	0.22	0.26	**-0.53**	0.13	0.05	0.29	0.07	1.00	
FrtWtRa	0.03	0.04	0.32	-0.26	0.00	-0.08	-0.01	0.25	-0.18	1.00
Fun_Bac	**-0.36**	-0.29	0.26	-0.21	0.01	-0.06	0.05	**0.42**	-0.35	**0.39**
Fungi	**-0.59**	-0.16	0.24	-0.03	0.03	-0.10	0.12	**0.54**	-0.28	0.18
Gneg	**-0.46**	0.04	0.11	0.23	0.04	-0.05	0.12	0.33	-0.12	-0.12
Gpos	**-0.52**	0.03	0.20	0.17	0.08	-0.03	0.16	**0.41**	-0.13	-0.03
K	-0.15	0.18	0.21	-0.20	-0.14	-0.16	-0.11	-0.05	0.29	-0.15
MBC	-0.05	**0.42**	0.35	**0.40**	**0.38**	0.23	0.27	-0.09	0.03	-0.10
Mg	-0.16	0.35	-0.19	0.08	-0.04	**0.40**	-0.13	-0.01	0.18	-0.21
ML_ha	**-0.38**	-0.23	0.25	-0.24	**-0.55**	**-0.60**	**-0.42**	0.05	-0.30	0.30
N	-0.28	0.17	0.18	-0.22	-0.22	-0.04	-0.20	0.07	0.17	0.23
NoFalls	0.09	0.26	-0.05	**0.39**	-0.09	-0.13	-0.03	0.03	-0.07	-0.07
NoFums	-0.18	0.08	0.23	**-0.43**	-0.27	-0.30	-0.06	0.07	0.15	0.03
NoGMs	-0.02	-0.26	0.03	-0.10	-0.16	-0.22	-0.03	0.11	-0.29	0.08
NoSolC	0.34	-0.06	0.13	**-0.36**	-0.06	0.06	-0.04	-0.12	0.30	0.13
NoWdSp	0.18	-0.16	-0.33	0.13	-0.07	0.09	-0.26	**-0.48**	-0.09	-0.18
Omniv	0.22	**0.52**	0.26	0.04	**0.99**	**0.70**	**0.77**	0.07	0.09	0.02
P	-0.04	**0.57**	0.15	-0.05	0.04	0.16	0.03	0.14	**0.41**	-0.25
pH0_15	0.20	-0.13	0.09	-0.29	0.14	0.29	0.12	0.33	0.29	0.01
pH45_60	-0.20	-0.18	**0.49**	-0.33	0.18	-0.04	**0.36**	**0.56**	-0.08	**0.50**
PLFAME	**-0.50**	0.00	0.19	0.19	0.04	-0.05	0.11	**0.37**	-0.13	-0.05
Roots	-0.05	0.21	0.28	-0.26	0.07	0.06	0.27	0.23	0.19	0.15
S	-0.28	0.30	-0.16	0.03	-0.05	0.34	-0.09	0.02	0.11	-0.25
SurfCrt	-0.10	-0.06	-0.09	-0.25	-0.13	-0.22	0.00	-0.14	0.28	0.08
TotBac	**-0.50**	0.03	0.17	0.19	0.07	-0.04	0.15	**0.39**	-0.13	-0.06
TotC	0.25	0.31	-0.15	**0.75**	0.29	0.27	0.20	-0.29	-0.22	-0.33
TotFLN	0.03	**0.48**	**0.37**	-0.02	**0.80**	0.34	**0.88**	**0.40**	0.20	-0.04
TotN	-0.11	0.21	0.24	0.24	0.20	0.02	0.29	-0.12	0.05	-0.00
TotPara	0.07	-0.25	-0.15	0.34	-0.11	-0.16	-0.27	-0.27	**-0.40**	-0.02
TotPass	-0.14	0.27	**0.44**	-0.11	0.35	0.21	0.33	0.19	-0.01	0.23
TotRot	**0.42**	-0.30	-0.28	0.15	-0.16	-0.11	-0.25	**-0.41**	0.13	-0.32
VAM	-0.33	-0.04	0.35	0.01	0.16	0.03	0.26	**0.52**	-0.11	0.15
WeedPr	0.23	0.30	0.35	-0.27	-0.03	-0.05	0.11	0.00	**0.38**	0.17
WtMktFr	-0.26	0.08	0.08	-0.24	0.06	0.06	0.06	0.23	0.13	**0.45**
Yld5Yrs	0.00	**0.46**	**0.45**	-0.14	0.20	0.18	0.16	0.21	0.16	0.07

	Fun_Bac	Fungi	Gneg	Gpos	K	MBC	Mg	ML_ ha	N	No. Fallows	No. Fumigs
Fun_Bac	1.00										
Fungi	**0.80**	1.00									
Gneg	0.29	**0.74**	1.00								
Gpos	**0.43**	**0.84**	**0.95**	1.00							
K	-0.32	-0.24	-0.12	-0.10	1.00						
MBC	-0.05	0.12	0.26	0.29	0.03	1.00					
Mg	-0.33	-0.24	-0.07	-0.08	0.22	-0.06	1.00				
ML_ha	**0.37**	0.34	0.19	0.24	0.14	-0.18	-0.29	1.00			
N	0.01	0.05	0.13	0.20	0.27	-0.10	**0.44**	0.35	1.00		
NoFalls	-0.08	0.04	0.22	0.12	-0.26	0.15	-0.07	-0.02	-0.13	1.00	
NoFums	0.01	-0.13	-0.28	-0.25	**0.51**	-0.18	0.00	**0.49**	0.05	-0.20	1.00
NoGMs	0.34	0.17	-0.18	-0.11	0.22	-0.27	-0.26	0.25	**-0.38**	-0.25	**0.55**
NoSolC	0.07	-0.26	**-0.46**	**-0.50**	-0.04	-0.31	-0.07	0.00	-0.21	-0.11	**0.43**
NoWdSp	-0.35	**-0.45**	**-0.46**	**-0.51**	-0.21	-0.02	0.05	-0.19	**-0.40**	0.03	-0.09
Omniv	0.00	0.02	0.02	0.05	-0.14	**0.37**	-0.07	**-0.50**	-0.26	-0.11	-0.22
P	**-0.36**	-0.27	-0.06	-0.09	**0.54**	-0.08	**0.48**	-0.09	0.27	0.17	0.34
pH0_15	0.14	-0.05	-0.16	-0.11	-0.18	-0.08	0.14	-0.25	-0.01	0.19	-0.20
pH45_60	**0.67**	**0.70**	**0.43**	**0.56**	-0.28	0.15	**-0.46**	0.31	0.14	-0.03	-0.14
PLFAME	**0.42**	**0.84**	**0.96**	**0.99**	-0.15	0.28	-0.09	0.24	0.17	0.20	-0.29
Roots	-0.07	-0.04	-0.02	-0.02	0.20	0.05	0.07	0.05	0.09	-0.29	0.25
S	-0.24	-0.16	-0.08	-0.05	**0.40**	-0.07	**0.93**	-0.19	0.35	-0.24	0.23
SurfCrt	-0.05	-0.13	-0.33	-0.24	0.20	-0.18	-0.21	0.09	0.07	-0.24	**0.41**
TotBac	**0.39**	**0.81**	**0.98**	**0.99**	-0.11	0.28	-0.07	0.23	0.18	0.16	-0.26
TotC	-0.21	0.02	0.28	0.21	-0.19	0.35	-0.01	**-0.37**	-0.31	0.30	**-0.42**
TotFLN	0.10	0.29	0.31	0.34	-0.04	**0.39**	-0.22	**-0.36**	-0.22	0.11	-0.10
TotN	0.08	0.34	**0.44**	**0.43**	-0.02	**0.43**	-0.22	-0.02	-0.10	0.05	-0.11
TotPara	-0.28	-0.16	-0.04	-0.05	0.09	0.01	-0.10	0.07	0.08	-0.08	-0.28
TotPass	0.33	**0.49**	**0.48**	**0.54**	0.10	0.28	-0.20	0.23	0.21	-0.08	-0.05
TotRot	**-0.38**	**-0.51**	**-0.39**	**-0.50**	**0.36**	-0.16	-0.18	-0.29	**-0.44**	-0.08	0.05
VAM	**0.61**	**0.85**	**0.81**	**0.87**	-0.27	0.20	-0.24	0.19	0.11	0.29	-0.33
WeedPr	-0.28	**-0.44**	-0.33	-0.32	**0.38**	0.01	0.04	0.02	0.18	0.07	0.34
WtMktFr	0.24	0.32	0.07	0.24	-0.00	0.02	0.07	0.14	**0.46**	-0.11	-0.08
Yld5Yrs	-0.19	-0.07	0.11	0.11	**0.61**	0.14	0.22	0.08	**0.46**	-0.10	0.18

	NoGMs	No. Sol Crops	No. Weed Sp	Omniv	P	pH0_15	pH45_60	PLFAME	Roots	S	SurfCrt
NoGMs	1.00										
NoSolC	0.34	1.00									
NoWdSp	-0.13	0.21	1.00								
Omniv	-0.13	-0.06	-0.04	1.00							
P	-0.06	-0.01	-0.29	0.02	1.00						
pH0_15	-0.29	0.05	0.00	0.07	0.13	1.00					
pH45_60	0.03	-0.19	**-0.47**	0.16	**-0.41**	0.27	1.00				
PLFAME	-0.14	**-0.47**	**-0.46**	0.01	-0.11	-0.08	**0.54**	1.00			
Roots	0.04	0.22	-0.09	0.08	0.02	-0.14	0.10	-0.07	1.00		
S	0.04	-0.10	-0.00	-0.06	**0.52**	0.01	**-0.44**	-0.09	0.08	1.00	
SurfCrt	0.34	0.23	-0.06	-0.12	0.15	-0.30	-0.09	-0.30	-0.06	-0.04	1.00
TotBac	-0.13	**-0.49**	**-0.50**	0.05	-0.08	-0.13	**0.52**	**0.99**	-0.02	-0.06	-0.27
TotC	0.03	-0.17	0.05	0.27	0.01	**-0.38**	-0.24	0.24	-0.05	-0.02	-0.11
TotFLN	-0.06	-0.17	-0.34	**0.78**	0.11	0.01	**0.36**	0.29	0.10	-0.18	-0.02
TotN	0.12	0.03	-0.13	0.20	-0.17	**-0.49**	0.18	**0.42**	0.29	-0.18	0.10
TotPara	-0.21	**-0.43**	0.27	-0.08	-0.30	-0.24	-0.11	-0.05	-0.28	-0.12	-0.09
TotPass	0.00	-0.18	-0.34	0.34	0.00	-0.09	**0.55**	**0.52**	0.15	-0.14	-0.15
TotRot	0.26	0.32	0.27	-0.17	0.13	-0.02	**-0.52**	**-0.47**	-0.08	-0.13	0.22
VAM	-0.10	-0.32	**-0.52**	0.11	-0.19	0.21	**0.79**	**0.89**	-0.05	-0.27	-0.33
WeedPr	0.04	0.02	-0.21	-0.04	**0.47**	0.25	-0.01	-0.34	-0.02	0.08	0.23
WtMktFr	-0.15	-0.17	-0.12	0.03	0.06	0.07	**0.38**	0.20	0.04	0.09	0.32
Yld5Yrs	-0.22	-0.18	-0.35	0.17	**0.40**	-0.03	0.06	0.08	**0.37**	0.22	-0.22

	Tot Bac	Tot C	Tot FLN	Tot N	Tot Para	Tot Passes	Tot Rotaries	VAM	Weed Pressure	Wt Mkt Frt	Yld 5 Yrs
TotBac	1.00										
TotC	0.24	1.00									
TotFLN	0.33	0.27	1.00								
TotN	**0.43**	**0.64**	**0.39**	1.00							
TotPara	-0.05	0.01	-0.19	-0.19	1.00						
TotPass	**0.53**	0.09	**0.44**	**0.47**	-0.24	1.00					
TotRot	**-0.47**	0.14	-0.25	-0.04	0.16	**-0.36**	1.00				
VAM	**0.86**	0.10	**0.40**	0.34	-0.17	**0.58**	**-0.50**	1.00			
WeedPr	-0.33	-0.27	0.02	-0.21	-0.22	0.07	0.12	-0.21	1.00		
WtMktFr	0.19	-0.14	0.11	0.19	-0.16	**0.48**	**-0.39**	0.24	-0.03	1.00	
Yld5Yrs	0.11	-0.13	0.21	-0.06	0.18	0.26	-0.14	0.08	0.16	0.02	1.00

MULTIPLE REGRESSION ANALYSIS

Multiple regression analysis of selective data from Tasmania on carrot productivity. Data selected for analysis in the multiple regression have significant correlation coefficients (p=0.05) in the initial analysis with a matrix of all possible pairwise simple correlation.

1. CARROT YIELD

Multiple Regression Analysis

Dependent variable: Market_carrot

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	51.9956	13.9326	3.73192	0.0008
pen300	-0.0118298	0.00574767	-2.05818	0.0481
rotarpass	7.78343	3.52628	2.20727	0.0348
%BFN	0.411286	0.194608	2.11341	0.0427

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	5398.84	3	1799.61	5.78	0.0029
Residual	9656.46	31	311.499		
Total (Corr.)	15055.3	34			

R-squared = 35.8601 percent
R-squared (adjusted for d.f.) = 29.653 percent
Standard Error of Est. = 17.6493
Mean absolute error = 12.5793
Durbin-Watson statistic = 1.93275

The equation of the fitted model is
Market_carrot = 51.9956 - 0.0118298*pen300 + 7.78343*rotarpass + 0.411286*%BFN

2. PACKOUT

Multiple Regression Analysis

Dependent variable: %Packout

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	76.4042	4.96813	15.3789	0.0000
misshapen	-0.672855	0.210435	-3.19744	0.0032
%Disease	-0.910958	0.13428	-6.78403	0.0000
TotalC	0.249048	0.0963379	2.58515	0.0147

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2292.54	3	764.179	22.03	0.0000
Residual	1075.45	31	34.6918		
Total (Corr.)	3367.98	34			

R-squared = 68.0686 percent
R-squared (adjusted for d.f.) = 64.9784 percent
Standard Error of Est. = 5.88997
Mean absolute error = 3.82877
Durbin-Watson statistic = 2.34629

The equation of the fitted model is
Packout = 76.4042 - 0.672855*mishape - 0.910958*perDIS + 0.249048*TotC

3. %DISEASES CARROT

Multiple Regression Analysis

Dependent variable: %Disease

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	10.978	5.14045	2.13561	0.0405
penetrometer150	0.0184657	0.00656056	2.81466	0.0083
Erosion	-5.6781	1.57283	-3.61013	0.0010

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	838.713	2	419.357	11.67	0.0002
Residual	1149.75	32	35.9298		
Total (Corr.)	1988.47	34			

R-squared = 42.1789 percent
R-squared (adjusted for d.f.) = 38.5651 percent
Standard Error of Est. = 5.99415
Mean absolute error = 4.15901
Durbin-Watson statistic = 2.30391

The equation of the fitted model is
%Disease = 10.978 + 0.0184657*penetrometer150 - 5.6781*Erosion

4. % MISSHAPEN

Multiple Regression Analysis

Dependent variable: %misshapen

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	8.56485	1.61307	5.30967	0.0000
Weed noQ35	1.36475	0.513895	2.6557	0.0122
rotarpass	-1.75212	0.838172	-2.09041	0.0446

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	213.912	2	106.956	5.73	0.0075
Residual	597.347	32	18.6671		
Total (Corr.)	811.258	34			

R-squared = 26.3679 percent
R-squared (adjusted for d.f.) = 21.7659 percent
Standard Error of Est. = 4.32054
Mean absolute error = 3.71076

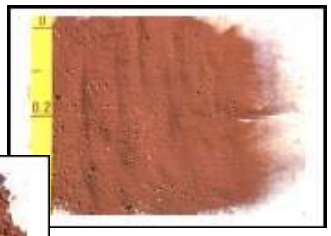
Appendix 4 – Soil structure scorecard

Soil structure scorecard

For clay loam textured topsoils in Tasmania

Score 1 – 2
Large compact clods (50 – 100 mm) with few fine aggregates.
Clods are angular or plate-like with smooth sides and no pores.

Score 3 – 4
Mainly firm large clods (20 – 50 mm) that are angular with smooth faces and no pores. Clods and overworked soil break into loose powdery soil.



Score 5 – 6
Few medium and large firm, rounded aggregates (5 – 30 mm) with mostly finer aggregates (< 2 mm) and some powdery unaggregated soil.

Score 7 – 8
Friable soil with many rounded aggregates (5 – 20 mm). Many fine rounded aggregates (< 2 mm) but little powdery unaggregated soil.

Score 9 – 10
Porous loose soil with many rounded, irregular shaped aggregates (2 – 10 mm). Large aggregates have many holes for good aeration and drainage. Little or no powdery unaggregated soil.
Often has abundant very fine roots.

For further details contact Bill Cotching ph 6421 7653

Natural Heritage Trust
Helping Communities Helping Australia

TIAR

NEWS Release

...618 Camp Cable Rd, Logan Village, QLD 4207 Ph/Fax: (07) 5547 7404 Mob: (0409) 477 404...

20 November 2000

Towards healthier vege soils

Do healthy soils produce healthier vegetable crops? How does vegetable production affect soil health? How can soil health be measured?

The Horticulture Research and Development Corporation (HRDC) has funded a two-year project until September 2002 to conduct preliminary investigations to begin finding answers to these questions and more.

Project leader, Dr Jason Olsen, a DPI research horticulturalist, says anecdotal evidence suggests that root and soil health problems may be important factors limiting vegetable production in Australian crops. “This will be one of the first projects to go out and try to quantify how healthy vegetable-producing soils are,” he said.

An improved understanding of how cultivation and production practices impact on soil and root health will help farmers keep their soils healthier, helping to sustain grower profitability and minimising soil degradation such as acidification and organic matter rundown.

Dr Leigh Sparrow, Program Manager with HAL, said that Australian vegetable growers, together with HAL, were keen to invest in the project because soil-borne diseases can be serious problems in many areas, and because the effects that soil conditions can have on the severity of soil-borne diseases are not well understood for vegetable systems.

“If an index of soil health could be developed, and then related to farm practices, growers would be in a much better position to manage their soils to minimise disease,” he said.

“The first step is to understand how serious disease problems are, and whether there is a clear link to soil physical and chemical properties. The next step will be developing and refining farm practices which try to improve the situation”, Dr Sparrow said.

“Whether we take that next step depends on the findings of this initial work.”
Dr Sparrow also said it was also very pleasing to see that the project involved collaboration of scientists in the public and private sectors across a number of states.

“This adds to the quality of the science and to the impact of the project's findings,” he added.

Dr Olsen said that the scientists will begin the project by collecting top-soil and sub-soil samples from farms and reference points in vegetable producing districts in Queensland, New South Wales, Victoria and Tasmania.

“The samples will be sent to a laboratory where the chemical, biological and physical properties will be analysed and used to develop a prototype index of soil health,” he explained.

“It will also give us a good snapshot of soil health at the moment on a district basis.”

Scientists hope that this will lead to a new type of soil testing service available to farmers. “Eventually they may be able to send a soil sample to the lab, to find out where they are on the soil health scale. It will tell them about beneficial and problem aspects of their soil,” he said.

One of the team soil scientists, Dr Phil Moody from DNR, said that a healthy soil is one that is able to carry out its functions in the ecosystem. “Healthy soil allows water to infiltrate, has a diverse microbial population which efficiently recycles nutrients such as nitrogen, phosphorus and sulphur, has physical properties which allow establishment of a good seedbed, and is fertile – with a good pH and balanced nutrient supply,” he explained.

The soil test results will also be looked at in conjunction with cultivation, cropping history and cropping practice information provided by the farmers who own the land samples were taken from.

“This will give us a preliminary indication of whether there are ‘healthy’ or ‘unhealthy’ farm practices,” Dr Olsen added.

Dr Moody said that by the end of the project we expect to have a much better idea of how vegetable production impacts on soil health, and leads into how production systems could change to enhance soil health and yield ‘clean, green’ products.

“These ideas would need to be tested and refined as a focus of possible future work,” Dr Olsen concluded.

Picture caption: *The project team.* From left to right are: Hoong Pung (Serve-Ag), Steve Jackson (QDPI), Pam Cox (Serve-Ag), Marcelle Stirling (Biological Crop Protection), Phil Moody (DNR), Clive Pankhurst (CSIRO), Mark Hickey (NSW Agriculture), Bill Ashcroft (Vic Natural Resources and Environment), Jason Olsen (QDPI), Leigh Sparrow (HRDC), and Bill Cotching (Tas Dept Primary Industry and Fisheries).

NEWS Release

...618 Camp Cable Rd, Logan Village, QLD 4207 Ph/Fax: (07) 5547 7404 Mob: (0409) 477 404...

27 June 2001

Healthy soils improve yield and sustainability.

Scientists and farmers are one step closer to understanding how healthy soils used for vegetable production are, following an extensive national soil-testing survey. They believe that better root and soil health may be the next step forward in increasing vegetable yields and improving the sustainability of farming land.

Project leader, Dr Jason Olsen, a QDPI research horticulturalist, says that soil samples have been taken from around three-quarters of the crop sites due to be tested by the end of this year. In addition to taking soil samples, the scientists have asked the farmers whose soil was tested about the cropping history, crop yields and agricultural practices such as cultivation, irrigation and pesticide management.

"This data will help us to understand which practices have some impact on physical, biological and chemical aspects of soil health," Dr Olsen says.

This work is being funded by Horticulture Australia Ltd (formerly HRDC) as part of a two-year project to investigate the relationships between soil properties and the productivity and sustainability of vegetable production in Australia. The project involves collaboration between scientists from State Departments of Agriculture and Natural Resources from Queensland, New South Wales, Victoria and Tasmania as well as CSIRO and the private research organisations Serve-Ag Research and Biological Crop Protection Pty Ltd.

"By the end of the year, we aim to have taken 100 soil samples from vegetable crop sites and reference sites for comparison," explains Dr Olsen. "The soils tested cover a range of soil types from major production areas, including Bowen, Gumlu and Gatton (QLD), Bundaberg (QLD), Forth (TAS), Robinvale (VIC) and Griffith (NSW)."

"All the crop sites tested in Queensland were growing capsicums, whereas all sites in New South Wales, Victoria and Tasmania are carrot producing soils," he adds.

Most of the soil samples are still undergoing extensive analysis (see table below), but according to Dr Phil Moody, principal soil scientist, QDNRM, subsoil salinity

has been detected at some sites, and a couple of Bundaberg sites have shown high levels of root galling from root-knot nematode.

However, Dr Olsen says that without a full analysis of the data, it is too early to comment on the significance of these findings.

Soil test	*What it tells us*
pH	Soil alkalinity/acidity, which affects nutrient availability, soil microbe populations and plant health.
Electrical conductivity	Soil 'saltiness' to give us an idea of whether salinity at depth is likely to impact on future production.
Aggregate stability, compaction levels	How easy is it for roots to penetrate and for air to reach roots to help them grow?
GC FAME	Measures the diversity of micro-organisms (e.g. bacteria and fungi) in the soil.
Total microbial activity & populations of free-living nematodes	May give an indication of soil suppressiveness to fungal pathogens and nematode pests.
Labile carbon levels	Measures the active soil carbon, which is important for key soil chemical, physical and biological properties.
Soil type classification	Accurate classification of soils will help analyse results and relate them to the same or similar soils in other areas.

Once the results from all the soil tests are completed, they will be entered into a database along with the information on how these soils have been managed. "This will give us a preliminary indication of whether there are 'healthy' or 'unhealthy' farm practices," Dr Olsen says.

"We will be conducting industry forums in Bundaberg and Bowen next year to discuss results and implications with growers and other interested stakeholders," he adds. Serve-Ag will be also be conducting a forum to discuss results with the carrot industry in Tasmania, and Mark Hickey, NSW Agriculture, reports a strong interest from carrot growers at Griffith in learning of project outcomes. He says a grower/ industry forum will also be run in Griffith in mid 2002.

The team of scientists hope that the final outcome of their work will be some ideas to be tested, on which practices farmers can use to improve soil health for different soil types, leading to more productive and sustainable vegetable production.

NEWS Release

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7 February 2002

Soil Health Forum for Bowen and Bundaberg districts

Do you know how healthy your soils are? What are the implications of crop management practices on the health of your soils, plant roots and crop yields? How can soil health be measured?

The answers to these questions and more will be discussed at an industry forum on soil health at the DPI Centre for Dry Tropics, Bowen, on Wednesday 20th February 2002 from 3:30 to 6:30 pm and at DPI, Bundaberg Research Station, Bundaberg on Wednesday 20th March from 3:30 to 6:30 pm. All vegetable and horticultural producers, crop consultants and others interested in soil health are invited to participate.

During the forum, Dr Jason Olsen, project leader and a QDPI research horticulturalist, will discuss the results and implications of a study conducted in the area last year with vegetable growers, consultants and others interested in soil health. This work was part of a national study to discover how healthy the soils used for vegetable production are, and to determine which management practices have most impact on physical, biological and chemical aspects of soil health.

"We tested soil from capsicum cropping sites and asked the farmers about previous crop management practices on those sites," Dr Olsen explains. "Although the data was collected from capsicum fields, it can equally be applied to a wide range of horticultural crops grown in the area," he adds.

The results have shown that tillage for bed preparation and the amount of nitrogen applied to the crop are two important factors affecting crop yield. According to Dr Olsen, there are no surprises in this finding, but it fails to indicate the long-term impact of poor soil health on sustainable production.

Dr Phil Moody, Principal Soil Scientist with DNR, Brisbane, says that this phenomenon is like having an oil leak in your car – if you keep topping up the oil every day it will perform acceptably in the short term, but in the longer term it will have negative impacts on both your finances and the environment. He likens the introduction of practices to improve soil structure and diversity of soil microorganisms (creating a disease suppressing soil) with fixing the cause of the oil leak in the car.

Another aspect of the research was to study the composition of the community of microorganisms in soils under intensive vegetable production. This work was undertaken by Dr Clive Pankhurst, Senior Principal Research Scientist with CSIRO in South Australia, using a method based on analysis of fatty acids extracted from soil.

"We compared the microorganisms present in soils under intensive vegetable production with those present in an area of pasture immediately adjacent to the intensively cropped area," he explains.

This analysis showed that, generally, there was less than half the amount of microorganisms in the soils under vegetable production compared with the soil in the pasture sites. "In particular, the amount of soil fungi, including beneficial mycorrhizal fungi in the cropped soils, was as little as one-tenth of that in the reference soils," Dr Pankhurst explains.

He says that the loss of soil fungi is an indicator of poor soil health because fungi carry out valuable functions in the soil such as holding soil particles together (giving the soil its structure) as well as capturing and retaining nutrients.

The work in this project is being funded by Horticulture Australia Ltd (formerly HRDC) as part of a two-year project to investigate the relationships between soil properties and the productivity and sustainability of vegetable production in Australia. The project involves collaboration between scientists from State Departments of Agriculture and Natural Resources from Queensland, New South Wales, Victoria and Tasmania, as well as CSIRO and the private research organisations Serve-Ag Research and Biological Crop Protection Pty Ltd.

The team of scientists hope that the final outcome of the discussions and of the project will be some ideas to be tested, on which practices farmers can use to improve soil health for different soil types, leading to more productive and sustainable vegetable production.

A similar industry forum for the carrot industry will be held in Tasmania later in the year.

For more information on the forums, contact Steve Jackson on (07) 4155 6244.

Ends.

Photos available from Larissa Bilston
Ph/fax (07) 3200 3021
Email larissa@bilston.com.au

Appendix 6 - Feedback from Industry Forums in Queensland

Feedback

from Bowen Industry Forum, 21 May 2002

1. What can horticultural industry learn from these results?

- Must be truly objective when trying new products (need a control/benchmark) and beware of sales push.
- Will we rely on good genetics in future to overcome poor soil health?
- Are crop fallow practices better or worse than rotations?
- Is soil health too hard? A proportion of industry has opted to move to hydroponic type systems.

2. What actions, if any, need to be taken to improve soil health?

- Research to examine organic amendments and N levels needed to answer some of the questions raised – need long-term trials to test labile C hypothesis.
- Need long-term trials to examine these factors, which may take 8-10years to show to look at soil health factors.
- What do you have to do to get a very healthy soil?
- Water is really scarce in the dry tropics – this impacts on organic matter in soils. Healthy soil management will be different in different environments/climates.
- What information would be shown if the same sites were re-sampled? Could hone in on management techniques on individual sites.

3. What are/should be the industry priorities regarding soil health?

- What practices lead to healthy soils in the long-term in different environments?
- Need much more data, similar to that collected so far, to get better answers.

4. What things did you find most useful about the forum?

- Overall results of N and cultivation having the most effect on yield. This revealed the complexity of the whole area of soil health.
- The results.
- Simply, the information and statistics presented.
- Informal discussion with Jason.
- Information supplied from questions and answers.
- Those present seemed to be working towards or looking for some answers to achieving healthy soil.
- Information concerning biological additives and cultivation rate.
- Information on bioadditives.
- I am convinced that soil health problems are the key to success for me. However, Jason's results don't show that. Had the work continued for another five years, then I am confident that soil health factors (labile carbon levels, etc) would show up as key factors for optimum production.
-

5. What did you enjoy the most about the forum?

- The informality and discussion periods which developed.
- Is our future in soil health or chemical farming?
- Jason's presentation.
- General group discussion.
- Group activity.
- Graphs on findings.

6. What could we do to improve future forums in other districts?

- I thought it to be very good.
- Get more growers/producers to participate.

7. Are you likely to change the way you do things as a result of the forum? If so, please describe.

- No since there were no outstanding messages to act on.
- Thinking along those lines.
- More soil, sap tests, etc, through the life of the crop.
- Continue to try and improve soil with cover crops and bioadditives.
- No.
- Not as yet.

8. Where did you hear about the forum?

- Bowen Independent first and a letter in the mail.
- Radio.
- Newspaper and ABC radio.
- Invitations through mail.
- ABC radio.

Feedback

from Bundaberg Industry Forum, 21 May 2002

1. What can horticultural industry learn from these results?

- Soil health is not clear-cut.
- We need benchmarking for soil health indicators to determine where we are at, and what has changed in future.
- We need to learn to use our soil more sustainably (avoiding short-term fixes).
- We need to maintain our research work and therefore need to keep our researchers.

2. What actions, if any, need to be taken to improve soil health?

- We need benchmarking for soil health indicators to determine where we are at and what has changed in future.
- Need research into organic amendments because we don't know for sure if they work. Growers could be wasting a lot of money.
- Farming systems could change to not relying on monocultures. Look at environmental, financial and social components. A novel way of achieving this could be to encourage or facilitate movement around farms at regional level to provide rotations on one piece of ground.
- If farmers are more pro-active about soil health, it could avoid harsh legislation in the future, e.g. nitrate levels in groundwater.
- Need awareness and education campaigns to guide farmers away from using muriate fertilisers. Although cheaper, they add chlorine to the soil.
- Need to raise awareness of what can be done with contour banks and drainage to control erosion.
- If problems are regional, need education, communication and possibly government incentives to entice industry to work together.

3. What things did you find most useful about the forum?

- Aspects of soil health – grower findings, importance of labile carbon.
- Interaction between growers.
- Informal nature.
- Interaction with researchers.
- Hearing about the microbial, fungi, et,c in soil, and testing for microbial activity.
- Discussion about C_1 relevance.
- How long it takes to build up organic matter.
- Reinforced what I already thought.
- The information on the individual micro-organisms.
- Little bits all through it.
- "New" methods of measuring soil health. Plus 'failure' of bioadditives.
- Research data.

4. What did you enjoy the most about the forum?

- Research findings and research techniques.
- The knowledge being imparted.
- The data presented by Jason.
- Grower input.
- Hearing about the soil tests at the research station and that the bio-products didn't work well.
- Open forum.
- Group activity.
- Smoko.
- Second part on results of the survey work.
- Mix of presentation, question time and group work.

5. What could we do to improve future forums in other districts?

- More cooperative technology (for presentations!).
- Give more time to absorb information.
- More data on soil health covering other workers around the world.
- More research.
- Field day – cover crops, mulches, irrigation scheduling.
- Need to continue to present results of research, answers to questions.
- Provide more detail on improving microbe populations.
- Make it simpler.
- 6.30pm is very late to finish after a days work.
- Well done.

6. Are you likely to change the way you do things as a result of the forum? If so, please describe.

- Use findings/knowledge.
- Happy to proceed along our present path but need more info.
- Investigate the application of green manures and other organic additives.
- Not really - Continue to learn more and try to apply it.
- Already practicing organics.
- Build up organic matter with green manure crops.
- Incorporate cover crops in time to decompose.
- No.
- Probably not.
- Yes, never get involved in soil health research – will pick on something easier!
- The forum helped to reinforce what I really know I have to do anyway re green manure cropping, etc.

7. Where did you hear about the forum?

- Good Fruit and Vegetables magazine.
- Fruit and Vege News.
- Local grower newsletter (3).
- Newspaper.
- Queensland Country Life.
- Word of mouth.
- Letter from Jason.

Appendix 7 – Data generated for analysis

	Number of free-living nematodes (FLN) per 200 mL soil (extracted)							No. of plant parasitic nematodes per 200 mL soil (corrected count										Log of Colony forming units				
Site ID	**FFN**	**BFN**	**Omniv**	**Total FLN**	**%FFN**	**%BFN**	**Ratio FF:BF**	**Lesion**	**Spiral**	**Rkn**	**Stunt**	**Cyst**	**Stubby**	**Pin**	**Renif**	**Total Paras**	**FDA**	**Total bact**	**Total G + Bacteria**	**Fluo. Pseu**	**Total fungi**	**Actino**
Q 1	220	1045	0	1265	17	83	0.21	0	0	0	0	0	0	0	0	0	0.099	7.22	6.590	5.22	5.39	7.30
Q 2	217	1855	2	2074	10	89	0.12	0	0	0	0	0	0	0	0	0	0.089	7.04	6.300	3.59	3.93	7.21
Q 3	45	3115	0	3160	1	99	0.01	0	0	0	0	0	0	0	0	0	0.030	6.59	7.390	4.59	4.53	7.22
Q 4	71	1455	0	1526	5	95	0.05	8	5	0	0	0	0	0	0	13	0.062	7.22	6.30	4.22	4.59	6.81
Q 5	110	2435	1	2546	4	96	0.05	0	0	0	0	0	40	0	0	40	0.193	7.39	5.220	5.22	5.06	7.58
Q 6	86	1645	1	1732	5	95	0.05	0	0	0	5	0	0	0	0	5	0.217	7.81	6.380	5.22	4.81	5.08
Q 7	46	890	2	938	5	95	0.05	0	0	0	0	0	0	0	0	0	0.143	7.53	6.590	4.81	5.08	6.74
Q 8	42	165	11	218	19	76	0.25	0	0	0	1	0	0	0	0	1	0.171	7.22	6.040	5.22	5.22	6.13
Q 9	160	3250	2	3412	5	95	0.05	0	0	0	0	0	0	0	0	0	0.146	8.04	6.530	6.30	3.74	7.39
Q10	1360	1070	55	2485	55	43	1.27	0	0	0	0	0	0	0	0	0	0.202	7.30	6.390	4.39	5.30	7.53
Q11	355	910	0	1265	28	72	0.39	0	0	0	0	0	0	0	0	0	0.053	7.53	7.30	5.59	5.00	7.00
Q12	195	765	0	960	20	80	0.25	72	0	0	0	0	18	0	0	90	0.096	6.39	5.740	5.39	5.22	7.06
Q13	15	735	1	751	2	98	0.02	0	0	0	0	0	0	0	0	0	0.085	7.06	6.590	4.06	4.39	7.04
Q14	140	755	5	900	16	84	0.19	0	0	0	0	0	0	0	0	0	0.120	8.67	7.530	3.81	5.39	6.53
Q15	260	830	12	1102	24	75	0.31	0	2	0	0	0	0	0	0	2	0.158	7.93	8.130	3.18	4.59	7.53
Q16	150	1920	8	2073	7	93	0.08	0	0	0	0	0	0	0	0	0	0.292	6.53	5.930	4.59	4.81	7.53
Q17	280	1942	15	2237	13	87	0.14	12	4	0	0	0	0	0	0	16	0.453	7.93	6.530	3.74	5.22	6.93
Q18	80	2170	3	2253	4	96	0.04	0	0	0	0	0	0	0	0	0	0.125	8.22	7.814	3.53	4.53	8.81
Q19	120	340	3	463	26	73	0.35	0	30	0	0	0	0	0	0	30	0.668	7.74	6.740	0.00	5.39	7.30
Q20	120	1330	1	1451	8	92	0.09	0	0	0	0	0	0	0	0	0	0.079	7.30	5.390	3.22	4.74	6.08
Q21	15	565	2	582	3	97	0.03	0	270	0	0	0	0	0	0	270	0.143	7.85	7.530	3.59	4.53	7.53
Q22	80	395	0	475	17	83	0.20	60	40	0	0	0	0	0	0	100	0.181	7.39	6.300	0.00	4.39	7.30
Q23	5	280	0	285	2	98	0.02	0	0	0	0	0	0	0	0	0	0.038	5.74	6.530	3.53	4.08	8.30
Q24	175	480	3	658	27	73	0.36	0	0	0	0	0	0	0	0	0	0.215	8.39	7.000	2.93	3.39	8.00

	Number of free-living nematodes (FLN) per 200 mL soil (extracted)							No. of plant parasitic nematodes per 200 mL soil (corrected count										Log of Colony forming units				
Site ID	FFN	BFN	Omniv	Total FLN	%FFN	%BFN	Ratio FF:BF	Lesion	Spiral	Rkn	Stunt	Cyst	Stubby	Pin	Renif	Total Paras	FDA	Total bact	Total G + Bacteria	Fluo. Pseu	Total fungi	Actino
Q25	150	285	1	436	34	65	0.53	0	0	0	0	0	0	0	0	0	0.192	7.53	6.04	3.81	3.74	6.74
Q26	95	925	0	1020	9	91	0.10	70	110	0	0	0	0	0	0	180	0.640	8.53	7.30	0.00	5.74	7.74
Q27	42	1350	0	1392	3	97	0.03	0	12	0	0	0	0	0	0	12	0.088	7.39	5.74	3.85	3.22	6.22
Q28	150	1700	0	1910	8	89	0.09	0	5	0	0	0	0	0	0	5	0.084	7.59	5.53	4.39	2.74	6.74
Q29	10	2170	0	2180	0	100	0.00	0	0	0	0	0	0	0	0	0	0.207	8.59	8.04	2.93	3.39	8.39
Q30	15	315	2	332	5	95	0.05	0	2	0	0	0	0	0	0	2	0.089	7.30	5.35	0.00	4.59	6.30
Q31	45	295	1	341	13	87	0.15	0	0	0	0	0	0	0	0	0	0.056	7.22	6.22	0.00	5.39	6.93
Q32	50	380	4	434	12	88	0.13	0	0	0	0	0	0	0	0	0	0.063	7.22	6.22	0.00	5.39	6.93
Q33	50	735	4	789	6	93	0.07	0	0	0	0	0	0	0	0	0	0.093	7.04	6.04	3.59	3.74	6.59
Q34	500	2308	147	2955	17	78	0.22	0	0	0	0	0	0	0	0	0	0.026	7.53	7.22	3.39	5.39	6.39
Q35	360	980	466	1806	20	54	0.37	0	0	0	0	0	0	0	0	0	0.073	8.81	7.93	3.06	3.85	6.81
Q36	3050	3600	670	7320	42	49	0.85	0	0	0	0					0	0.207	7.53	6.81	4.08	5.39	6.24
Q1-1	440	885	5	1330	33	67	0.50	10	40	0	0	0	0	0	0	50	0.530	6.30	6.00	4.93	5.74	7.30
Q4-1	1545	455	10	2010	77	23	3.40	0	0	0	0	0	0	0	0	0	0.020	6.67	5.93	4.22	5.22	6.82
Q9-1	1680	930	41	2651	63	35	1.81	148	0	0	52	0	19	0	0	219	0.464	6.39	5.04	3.59	5.74	6.59
Q11-1	580	1564	32	2176	27	72	0.37	100	0	0	0	0	0	0	0	100	0.369	8.30	6.53	4.59	5.39	6.95
Q14-1	1110	580	54	1744	64	33	1.91	0	0	0	0	0	0	860	0	860	0.786	6.85	6.00	4.22	5.53	6.74
Q17-1	1370	500	22	1892	72	26	2.74	150	200	0	0	0	0	130	0	480	0.338	6.74	6.00	2.81	4.81	3.53
Q24-1	1392	670	30	2092	67	32	2.08	180	320	0	0	0	0	200	0	700	1.679	8.74	7.53	3.22	5.08	3.30
Q31-1	530	2000	39	2569	21	78	0.27	560	220	0	0	0	0	13	0	793	1.561	7.81	5.39	3.59	5.08	5.74

MBC = Microbial biomass carbon, C1 - 33mM KMnO4 oxidisable C (most useful for labile C), C3 - 333mM KMnO4 oxidisable C

	Depth 0-15 cm		Depth 45-60 cm		Depth 0 -15 cm								Penetrometer reading
SiteID	pHw	EC (mS/m)	pHw	EC (mS/m)	Total C (g/kg)	Total N (g/kg)	C:N	MBC (mg/kg)	C fract.1 (g/kg)	C fract. 3 (g/kg)	C1/Tot C (%)	Aggregate Stability (%>0.5 mm)	Soil depth with maximum value
Q 1	7.76	43.2	9.27	36.8	9.5	0.70	14	53.7	0.78	1.12	8.2	43	600
Q 2	8.22	35.6	9.07	11.0	9.0	0.70	13	19.4	0.66	0.94	7.3	20	585
Q 3	6.22	41.3	8.54	21.9	10.2	0.90	11	35.1	0.95	1.64	9.3	27	360
Q 4	6.45	61.0	8.38	35.1	7.7	0.80	10	45.5	0.63	1.16	8.2	10	330
Q 5	6.42	24.8	8.04	7.3	11	0.80	14	19.8	1.10	1.99	10.0	5	240
Q 6	5.81	25.5	7.96	8.9	12.1	0.90	13	42.2	1.19	2.22	9.8	5	240
Q 7	6.68	13.3	7.76	6.6	7.2	0.40	18	9.9	0.59	1.33	8.2	3	555
Q 8	7.13	11.0	8.06	10.3	7.7	0.50	15	9.9	0.68	1.36	8.8	2	330
Q 9	6.54	16.5	9.31	18.7	15.1	1.09	14	43.8	1.16	2.88	7.7	4	255
Q10	5.91	8.4	7.88	4.2	8.4	0.68	12	27.3	0.79	1.51	9.4	9	585
Q11	7.56	17.9	8.45	7.7	8.1	0.59	14	10.7	0.79	1.25	9.8	3	555
Q12	7.95	22.9	9.08	14.5	9.8	0.71	14	37.6	0.69	1.20	7.0	13	555
Q13	7.30	7.9	9.48	10.6	5.6	0.46	12	28.5	0.45	0.84	8.0	8	600
Q14	7.57	23.4	5.46	8.6	14.9	0.58	26	2.5	0.86	2.18	5.8	11	570
Q15	7.84	17.6	5.86	8.7	10.1	0.70	14	6.5	0.89	1.90	8.8	11	585
Q16	7.39	39.6	5.89	7.5	11.3	0.56	20	35.3	1.01	2.35	8.9	20	480
Q17	7.59	43.4	5.72	6.0	15.9	0.70	23	59.8	1.16	2.82	7.3	11	600
Q18	5.86	42.3	5.75	1.9	12.9	0.70	18	16.2	1.07	2.06	8.3	5	495
Q19	6.03	57.5	5.57	6.5	25.1	1.00	25	49.3	1.51	3.30	6.0	10	585
Q20	6.95	12.4	6.24	11.7	10.0	0.74	14	10.1	0.76	1.93	7.6	13	600
Q21	6.70	9.7	6.83	10.8	5.6	0.43	13	16.6	0.34	0.85	6.1	15	495
Q22	7.37	11.6	5.82	6.5	9.7	0.41	24	9.4	0.81	1.68	8.4	9	420
Q23	7.74	22.8	4.76	9.6	6.5	0.38	17	11.9	0.39	0.59	6.0	7	570
Q24	6.57	69.0	4.48	3.9	13.6	0.64	21	18.0	0.94	2.26	6.9	10	315
Q25	7.18	57.2	4.83	11.3	8.4	0.58	14	35.3	0.63	1.21	7.5	44	435

	Depth 0-15 cm		Depth 45-60 cm		Depth 0 -15 cm								Penetrometer reading
SiteID	pHw	EC (mS/m)	pHw	EC (mS/m)	Total C (g/kg)	Total N (g/kg)	C:N	MBC (mg/kg)	C fract.1 (g/kg)	C fract. 3 (g/kg)	C1/Tot C (%)	Aggregate Stability (%>0.5 mm)	Soil depth with maximum value
Q26	4.62	28.8	5.39	4.2	19.4	0.89	22	55.8	1.01	2.53	5.2	29	570
Q27	6.16	75.5	5.26	17.0	6.6	0.52	13	17.0	0.47	0.99	7.1	8	435
Q28	5.95	38.2	4.93	18.7	12.9	0.76	17	30.3	0.86	2.06	6.7	31	495
Q29	6.00	46.2	5.25	12.1	11.4	0.71	16	15.9	0.90	1.81	7.9	30	495
Q30	5.49	23.3	5.76	12.5	14.5	1.08	13	15.0	0.93	2.14	6.4	6	495
Q31	5.55	25.0	6.33	3.5	10.5	0.79	13	20.5	0.66	1.30	6.3	6	525
Q32	7.36	20.4	6.00	9.0	5.5	0.63	9	69.6	0.43	0.75	7.8	11	345
Q33	7.60	20.0	7.02	4.68	8.7	0.62	14	31.9	0.73	1.40	8.4	2	435
Q34	8.14	86.5	8.48	17.2	19.9	1.18	17	80.0	1.37	3.45	6.9	#	600
Q35	8.07	43.6	8.18	16.6	15.3	0.75	20	60.4	1.03	1.70	6.7	#	600
Q36	6.96	94.3	7.98	23.7	17.5	0.91	19	67.3	1.33	2.42	7.6	#	600
Q 1-1	6.95	8.0	9.33	80.2	17.4	1.30	13		1.94	3.05	11.1	45	
Q 4-1	6.56	5.1	8.59	11.6	25.2	1.50	17		2.45	4.08	9.7	80	
Q 9-1	5.88	5.2	8.65	140.0	9.2	0.60	15		0.71	1.58	7.7	33	
Q 11-1	6.72	6.0	9.07	25.8	17.1	1.00	17		1.90	3.01	11.1	56	
Q14-1	5.98	2.7	6.04	5.4	23.2	0.78	30		1.56	3.02	6.7	55	
Q17-1	5.41	2.2	6.11	3.9	10.6	0.41	26		0.63	1.36	5.9	43	
Q24-1	5.64	2.5	6.7	2.9	15.8	0.85	19		1.35	2.56	8.5	43	
Q31-1	5.69	3.9	5.6	0.8	32.2	1.66	19		2.63	4.39	8.2	28	

	PL-FAMEs analysis								Fertiliser Application (Elemental application in kg/ha)												
SiteID	Total bacteria	Gram+ve bacteria	Gram-ve bacteria	Fungi	Mycorrhizal fungi	Ratio fungi:bact.	Total PL-FAMEs	SiteID	N	P	K	S	Ca	Mg	Zn	Cu	Fe	B	Mo	Mn	Cl
Q 1	1.11	0.88	0.23	0.06	0.12	0.05	3.80	Q 1	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 2	1.67	1.16	0.51	0.05	0.17	0.03	5.10	Q 2	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 3	2.20	1.38	0.82	0.08	0.16	0.04	6.20	Q 3	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 4	1.61	1.10	0.51	0.11	0.14	0.07	5.20	Q 4	173.8	75.0	204.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 5	1.95	1.38	0.57	0.18	0.17	0.09	6.10	Q 5	140.1	60.0	185.4	47.1	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 6	3.64	2.47	1.17	0.18	0.20	0.05	10.70	Q 6	140.1	60.0	185.4	47.1	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 7	1.08	0.76	0.32	0.10	0.08	0.09	3.10	Q 7	99.1	25.7	77.0	79.3	21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8
Q 8	1.23	0.87	0.36	0.10	0.10	0.08	3.70	Q 8	99.1	25.7	77.0	79.3	21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8
Q 9	2.36	1.67	0.69	0.19	0.19	0.08	7.40	Q 9	101.6	25.7	117.9	94.8	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8
Q10	1.70	1.21	0.49	0.28	0.17	0.16	5.60	Q10	84.3	46.4	116.4	112.6	121.4	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q11	1.07	0.76	0.31	0.08	0.12	0.07	3.20	Q11	164.0	45.0	171.2	3.6	66.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q12	1.20	0.83	0.37	0.08	0.13	0.06	3.70	Q12	115.4	71.3	117.6	4.9	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q13	0.55	0.37	0.18	0.02	0.05	0.04	1.80	Q13	115.4	71.3	117.6	4.9	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q14	0.94	0.54	0.39	0.03	0.08	0.03	3.29	Q14	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q15	0.98	0.60	0.38	0.03	0.07	0.03	2.83	Q15	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q16	0.85	0.57	0.27	0.02	0.07	0.02	2.57	Q16	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q17	1.31	0.84	0.46	0.03	0.09	0.02	4.15	Q17	88.0	78.8	127.3	32.7	185.8	18.2	2.3	1.2	18.5	0.2	0.0	1.6	0.0
Q18	0.62	0.42	0.20	0.00	0.00	0.00	1.65	Q18	102.4	56.5	74.5	35.0	54.2	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Q19	1.39	0.90	0.49	0.05	0.09	0.03	4.61	Q19	69.9	61.4	80.5	43.9	49.6	2.0	0.0	0.1	0.7	0.0	0.0	0.1	0.0
Q20	0.55	0.40	0.15	0.03	0.04	0.05	1.90	Q20	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q21	0.59	0.41	0.19	0.00	0.02	0.00	1.86	Q21	118.8	15.2	239.8	49.1	97.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q22	1.11	0.79	0.32	0.04	0.07	0.04	3.88	Q22	156.4	94.5	157.5	71.3	70.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q23	0.31	0.22	0.09	0.00	0.00	0.00	0.90	Q23										M	M	M	M
Q24	1.37	0.95	0.42	0.02	0.04	0.01	3.79	Q24	223.8	136.7	304.4	537.4	1651.1	126.3	0.0	0.7	4.5	0.0	0.0	0.5	0.0
Q25	0.82	0.58	0.25	0.02	0.02	0.02	2.57	Q25	179.9	123.5	217.0	497.9	1611.9	116.6	0.0	0.7	4.5	0.0	0.0	0.5	0.0

	PL-FAMEs analysis								Fertiliser Application (Elemental application in kg/ha)												
SiteID	Total bacteria	Gram+ve bacteria	Gram-ve bacteria	Fungi	Mycorrhizal fungi	Ratio fungi:bact.	Total PL-FAMEs	SiteID	N	P	K	S	Ca	Mg	Zn	Cu	Fe	B	Mo	Mn	Cl
Q26	1.50	1.00	0.50	0.03	0.04	0.02	4.09	Q26	163.9	20.1	191.6	1.6	86.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q27	0.57	0.39	0.18	0.02	0.01	0.03	1.68	Q27	171.5	127.1	190.5	22.8	38.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q28	0.72	0.49	0.24	0.01	0.01	0.01	1.81	Q28	91.6	140.8	405.7	153.9	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q29	0.68	0.48	0.20	0.02	0.01	0.03	1.85	Q29	91.6	140.8	405.7	153.9	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q30	0.53	0.39	0.14	0.02	0.02	0.04	1.72	Q30	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q31	0.40	0.25	0.16	0.01	0.01	0.02	1.25	Q31	125.7	28.6	164.4	24.1	85.3	1.0	1.9	0.1	0.5	0.0	0.0	0.0	0.0
Q32	0.54	0.38	0.16	0.02	0.02	0.04	1.80	Q32	87.5	18.3	252.5	63.3	71.8	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q33	0.50	0.36	0.14	0.02	0.01	0.04	1.38	Q33	156.4	94.5	157.5	71.3	70.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q34	1.24	0.89	0.35	0.04	0.12	0.03	3.36	Q34	121.1	112.5	100.0	64.1	197.3	17.5	2.5	1.4	20.5	0.3	0.0	1.8	0.0
Q35	0.66	0.48	0.18	0.00	0.06	0.00	1.62	Q35	121.1	112.5	100.0	64.1	197.3	17.5	2.5	1.4	20.5	0.3	0.0	1.8	0.0
Q36	1.35	0.95	0.40	0.06	0.11	0.04	3.72	Q36	77.8	72.5	125.0	37.2	21.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q 1-1	2.97	2.13	0.84	0.27	0.28	0.09	10.3	Q1-1													
Q 4-1	1.51	1.06	0.45	0.19	0.14	0.12	4.80	Q4-1													
Q 9-1	2.26	1.59	0.67	0.45	0.21	0.20	8.50	Q9-1													
Q11-1	2.79	1.90	0.89	0.39	0.36	0.14	10.6	Q11-1													
Q14-1	1.87	0.95	0.91	0.25	0.13	0.13	7.13	Q14-1													
Q17-1	1.74	0.91	0.83	0.30	0.09	0.14	6.52	Q17-1													
Q24-1	2.80	1.76	1.04	0.26	0.25	0.09	9.95	Q24-1													
Q31-1	2.07	1.36	0.71	0.08	0.15	0.04	6.62	Q31-1													

	Fertiliser Application (Elemental application in kg/ha)								Fertiliser Application (Elemental application in kg/ha)						
SiteID	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**B**	**SiteID**	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**B**
T 1	54.0	78.0	102.0	0	0	0	0	**T27**	86.45	98.80	67.930	0	0	0	0
T 2	82.5	90.0	142.5	0	0	0	0	**T28**	33.00	36.00	57.000	0	0	0	0
T 3	67.5	97.5	120.0	7.5	0	0	0	**T29**	82.50	90.00	135.000	0	0	0	0
T 4	67.5	112.5	97.5	0	0	0	0	**T30**	66.00	72.00	108.000	0	0	0	1.2
T 5	67.5	97.5	120.0	7.5	0	0	0	**T31**	58.50	104.00	84.500	0	0	0	0
T 6	66.0	72.0	114.0	0	0	0	0	**T32**	112.00	128.00	88.000	0	0	0	0
T 7	35.0	40.0	27.5	0	0	0	0	**T33**	70.00	80.00	55.000	0	0	0	0
T 8	35.0	90.5	27.5	2.5	0	0	0	**T34**	51.87	59.28	40.755	0	0	0	0
T 9	76.5	110.5	144.5	0	0	0	0	**T35**	56.00	64.00	44.000	0	0	0	0
T10	76.5	110.5	144.5	0	0	0	0	**T37**	30.00	30.00	30.000	0	0	0	0
T11	67.5	112.5	97.5	0	0	0	0	**T38**	270.00	300.00	0.000	30.0	885.5	464.0	0
T12	67.5	97.5	120.0	7.5	0	0	0	**T39**	66.00	78.00	114.000	0	0	0	0
T13	55.0	60.0	95.0	10.0	0	0	0	**T40**	110.00	120.00	190.000	0	0	0	0
T14	70.0	80.0	55.0	0	0	0	0	**V2**	44.00		124.000		16.0	8.4	
T15	70.0	80.0	55.0	0	0	0	0	**V3**	44.00		124.000		16.0	8.4	
T16	27.5	30.0	47.5	0	0	0	0	**V4**	44.00		124.000		16.0	8.4	
T21	70.0	80.0	55.0	0	0	0	0	**N1**	27.70	22.70		19.8			
T22	54.0	60.0	0	0	0	0	0	**N2**							
T23	71.5	78.0	123.5	0	0	0	0	**N3**							
T24	71.5	78.0	123.5	0	0	0	0	**N5**	86.90	59.30		5.0			
T25	154.0	176.0	121.0	0	0	0	0	**N6**	51.00	32.60		40.7	74.0		
T26	84.0	96.0	66.0	0	0	0	1.2	**N7**	51.00	32.60		40.7	74.0		

	Average yield from 3 subplots at each site						Qtn 5	Qtn 7	Qtn 8	Qtn 9
SiteID	Tot wt all fruit t/ha	Wt mkt fruit t/ha	No.of mkt fruit/ha	Av wt mkt fruit g/fruit	Mkt frt wt ratio (%)	SiteID	Surface cover (1=clean 2=bit trashy 3=lot trashy)	Nematicides used on site (1-yes:2-no)	Do you regularly use irrig. sched? (1-yes:2-no)	Tot irrig. used for crop (ML/ha)
Q 1	61.3	52.6	228,146	230.5	86	Q 1	1	2	1	3
Q 2	65.6	46.3	205,924	224.6	71	Q 2	1	2	1	3
Q 3	47.0	34.8	152,591	228.1	74	Q 3	1	2	1	3
Q 4	45.8	37.9	164,443	230.6	83	Q 4	1	2	1	3
Q 5	59.6	61.2	343,700	178.0	77	Q 5	2	2	2	3
Q 6	57.9	49.9	226,664	220.1	65	Q 6	2	2	2	3
Q 7	39.3	32.1	164,443	195.5	82	Q 7	1	2	2	3
Q 8	38.3	29.5	157,035	187.9	77	Q 8	1	2	2	3
Q 9	71.4	42.6	188,146	226.4	60	Q 9	1	2	2	2.5
Q10						Q10	1	2	2	2.5
Q11	47.1	51.0	226,664	224.8	84	Q11	2	2	2	1.7
Q12	50.8	41.0	179,257	228.9	63	Q12	2	2	2	3
Q13	45.7	43.1	207,405	208.0	73	Q13	2	2	2	3
Q14	45.1	24.4	106,171	229.9	54	Q14	2	2	1	2
Q15	48.5	30.2	128,393	235.2	62	Q15	2	2	1	2
Q16	51.6	33.6	139,916	240.4	65	Q16	1	2	1	1.5
Q17	51.6	33.6	125,924	266.8	65	Q17	1	2	1	1.5
Q18	70.7	43.8	191,948	228.4	62	Q18	1	2	1	2
Q19	56.0	37.8	145,554	259.7	67	Q19	2	2	2	2.5
Q20	63.6	39.2	181,649	216.1	62	Q20	1	1	1	2.5
Q21	45.8	37.5	180,447	207.9	82	Q21	1	2	1	2.5
Q22	77.5	37.9	157,776	239.9	49	Q22	1	1	2	2.5
Q23	68.1	51.3	201,780	254.2	75	Q23	2	2	2	2.5
Q24	67.8	42.0	168,738	249.0	62	Q24	2	2	1	2
Q25	75.8	48.1	189,442	254.0	63	Q25	2	2	1	2
Q26	49.1	27.8	136,665	203.5	57	Q26	1	2	2	2.5
Q27	53.4	40.8	153,331	266.1	76	Q27	1	2	1	3.5
Q28	64.9	31.3	152,891	204.6	48	Q28	2	2	1	2.5
Q29	49.4	35.1	163,558	214.7	71	Q29	2	2	1	2.5
Q30	54.1	47.3	187,267	252.8	88	Q30	1	1	1	2.5
Q31	57.1	42.3	191,012	221.7	74	Q31	1	1	1	2.5
Q32	55.9	31.7	115,557	274.5	57	Q32	1	2	1	2.5
Q33	73.1	56.3	217,776	258.6	77	Q33	1	2	2	2.5
Q34						Q34	3	2	2	2.5
Q35						Q35	1	2	2	2
Q36	59.7	42.0	201,479	210.0	70	Q36	1	2	1	1

	Qtn 10	Qtn 13A	Qtn 13B	Qtn 15	Qtn 16	Qtn 17	Qtn 18	Qtn 19	Qtn 20	Qtn 21	Qtn 22	Qtn 23
SiteID	Deep cultivate? (1-yes:2-no)	Tot no. passes cultiv. equip for crop	Tot no. passes rotary hoe /power harrows	Erosion (0=none 1=severe 2=mod 3=little)	Tillage ease (Rating 0,1,2,3)	Cloddiness (Rating 0,12,3)	Surface crust (Rating 0,1,2,3)	To what extent is soil structure decline affecting the viability of your farming business? (Rating 0,1,2,3)	Infiltration (Rating 0,1,2,3)	Decomposition (Rating 0,1,2,3)	Smell (Rating 0,1,2,3)	How many 8 kg ctns of markt capsicum fruit do you estimate from the block we surveyed? (Rating 1,2,3,4)
Q 1	2	6	1	3	2	2	2	3	3	3	3	2
Q 2	2	6	1	3	2	2	2	3	3	3	3	2
Q 3	2	6	1	3	2	2	2	3	3	3	3	2
Q 4	2	6	1	3	2	2	2	3	3	3	3	2
Q 5	1	7	1	2	3	3	2	2	3	2	2	1
Q 6	1	7	1	2	3	3	2	2	3	2	2	1
Q 7	2	3	1	3	3	3	2	3	3	3	3	3
Q 8	2	3	1	3	3	3	2	3	3	3	3	3
Q 9	1	3	1	3	3	3	3	3	2	3	3	2
Q10	2	9	N/a	3	3	3	3		2	3	3	1
Q11	2	4	2	3	3	3	3	3	3	3	2	2
Q12	1	N/a	1	3	2	1.5	2.5	3	2.5	2	3	
Q13	1	N/a	1	3	3		2.5	3	2.5	2	3	
Q14	1	2	2	3	3	3	1	2	3	3	3	3
Q15	1	3	3	3	3	3	2	2	2	3	3	3
Q16	1	2	2	3	3	3	2	3	2	3	3	3
Q17	1	2	2	3	3	3	2	3	2	3	3	3
Q18	1	3	1	2	3	3	3	3	3	2	3	2
Q19	2	5	2	0	3	3	2	3	2	2	3	3
Q20	2	5	2	0	2	2	2	3	3	3	3	2
Q21	1	2	2	3	3	2	2	3	3	3	3	3
Q22	1	3	2	0	3	3	3	3	3	3	3	4
Q23	1	2	1	0	3	3	2	3	3	3	3	3
Q24	1	3	1	3	3	2	2		2	2	2	2
Q25	1	4	1	3	3	1	2		2	2	2	2
Q26	1	3	2	3	3	2	2	3	3	3	3	2
Q27	1	2	1	0	3	3	3	3	2	3	3	2
Q28	1	4	3	3	3	3	3	3	3	3	3	2
Q29	1	4	3	3	3	3	3	3	3	3	3	2
Q30	2	3	2	2	3	3	3	3	3	3	3	3
Q31	2	5	2	2	3	3	3	3	3	3	3	2
Q32	1	3	2	2	3	3	2	3	2	3	3	2
Q33	1	3	2	0	3	3	3	3	3	3	3	3
Q34	2	4	3	0	3	2	1	3	3	3	3	2
Q35	2	4	3	0	3	2	1	3	3	3	3	2
Q36	1	7	1	3	2	2	2	3	3	3	3	2

	Qtn 24	Qtn 25A	Qtn 25B	Qtn 26	Qtn 27	Qtn 28	Qtn 29	Qtn 30	Qtn 31	Qtn 32	Qtn 33	Qtn 34	Qtn 35
SiteID	Quality of produce (Rating 1,2,3,4)	Main cause of reduced pack-out (Rating 0,1,2,3,4)	Main cause of increased pack-out (Rating 0,1,2,3,4)	Crop appearance (Rating 0,1,2,3,4)	Nutrient deficiency (Rating 0,1,2,3,4)	Plant density (Rating 0,1,2,3,4)	Growth rate (Rating 0,1,2,3,4)	Roots (Rating 0,1,2,3,4)	Foliage (Rating 0,1,2,3,4)	Resists drought (Rating 0,1,2,3,4)	Resists pests and disease (Rating 0,1,2,3,4)	Weed pressure (Rating 0,1,2,3,4)	No. weed species present
Q 1	4	1	0	4	4	4	4	4	4	4	4	4	1
Q 2	4	1	0	4	4	4	4	4	4	4	4	4	0
Q 3	4	1	0	4	4	4	3	4	4	4	4	4	0
Q 4	4	1	0	3	4	4	4	4	4	4	4	4	0
Q 5	4	1,4	0	2	3	4	3	3	3	3	4	2	2
Q 6	4	1,4	0	4	4	4	4	4	4	4	4	2	1
Q 7	4	0	3	3	3	4	3	3	3	3	4	3	1
Q 8	4	0	3	3	4	3	3	4	3	3	4	3	2
Q 9	4	0	3	4	4	4	4	4	4	4	4	2	1
Q 10	3			3	3	3	3	3	3	3	3	3	2
Q 11	4	1,2	0	4	4	4	4	4	4	4	4	3	1
Q 12	3	3	0	4	4	4	4	4	3	4	4	4	1
Q 13	3	3	0	4	4	3	4	4	4	4	4	4	1
Q14	4	1	0	4	4	4	4	4	4	4	4	2	3
Q15	4	1	0	4	4	4	4	4	4	4	4	3	3
Q16	4	0	3	4	4	4	4	4	4	4	4	3.5	3
Q17	4	0	3	4	4	4	3.5	2	4	4	4	3.5	2
Q18	3	1,4	0	4	4	4	4	4	4	4	3	3.5	4
Q19	3	1,2	3	3	3	4	3	3.5	3	4	3	3	6
Q20	3	2	0	4	4	3	4	4	4	4	3.5	3	5
Q21	3	1	0	3	4	3	3	3.5	3.5	3.5	3	3	6
Q22	4	0	3	3	4	3	4	1.5	4	4	3	3.5	3
Q23	3	3	0	4	4	4	4	4	4	4	4	4	0
Q24	4	1,3	0	3.5	4	4	4	4	4	4	4	3.5	1
Q25	4	1,3	0	4	4	4	4	4	4	4	4	3	4
Q26	3	1,2	0	2.5	4	2.5	2.5	4	3	4	3	2	1
Q27	4	0	3	3	4	3.5	4	4	4	4	3.5	3	3
Q28	4	1,3,4	0	3	4	4	4	4	4	4	4	4	2
Q29	4	1,3,4	0	3.5	4	3.5	4	4	4	4	4	4	0
Q30	4	1	0	4	4	4	3	4	4	4	4	3	4
Q31	4	1	0	4	4	4	3	3.5	4	4	3.5	3	3
Q32	4	1	0	4	4	4	4	4	4	4	4	3	6
Q33	4	1	3	4	4	4	4	4	4	4	4	3.5	2
Q34	3			4	4	4	4	4	4	4	4	1	10
Q35	3			4	4	4	4	4	4	4	4	2	8
Q36	4			4	4	4	4	4	4	4	4	3	2

	Qtn 1A	Qtn 1B.	Qtn 1C.	Qtn 1D	Qtn 3	Qtn 6A	Qtn 6B.	Qtn 6C.	Qtn 14A.	Qtn 14B.	Qtn 14C.	Qtn 14D.
SiteID	No. Solan-aceous crops planted within the last 5 years	No. times Fumigant used on site within past 5 years	No. times site fallowed in past 5 years	No. times a green manure crop grown in past 5 years	Over last 5 years has yield increased, decreased, stayed the same? (Rating 1,2,3)	Has use of fertiliser increased in past 5 years? (Rating 1-yes:2-no)	Has use of soil fumigation increased in past 5 years? (Rating 1-yes:2-no)	Has use of nematicides increased in past 5 years? (Rating 1-yes:2-no)	Has ploughing become more difficult in past 5 years? (Rating 1-yes:2-no)	Are more dense clods being brought to the surface than previously within last 5 years? (Rating 1-yes:2-no)	Is there increased incidence of sealing or waterloggin g? (Rating 1-yes:2-no)	Is water infiltration rate decreasing ?(Rating 1-yes:2-no)
Q 1	4	2	0	1	3	2	1	2	2	2	2	2
Q 2	2	3	3	0	3	2	1	2	2	2	2	2
Q 3	3	4	2	0	3	2	1	2	2	2	2	2
Q 4	3	2	1	0	3	2	1	2	2	2	2	2
Q 5	1	1	2	2	2	1	1	2	2	1	2	2
Q 6	1	1	0	0	2	1	1	2	2	1	2	2
Q 7	4	4	0	5	1	2	2	2	2	2	2	2
Q 8	4	4	0	5	1	2	2	2	2	2	2	2
Q 9	4	3	1	4	1	2	2	2	2	2	2	2
Q 10	4	0	0	5	2	1	2	2	2	2	2	2
Q 11	5	0	0	1	3	2	2	2	2	2	2	2
Q 12	4	1	0	1	3	1	2	2	2	2	2	2
Q 13	1	1	0	0	3	1	2	2	2	2	2	2
Q14	5	0	2	0	3	2	2	2	2	2	2	1
Q15	7	1	0	0	1	2	2	2	2	2	2	1
Q16	3	0	4	0	1	2	2	2	2	2	2	2
Q17	3	0	4	0	1	2	2	2	2	2	2	2
Q18	2	2	0	0	1	2	1	2	2	2	2	2
Q19	3	0	4	2	1	2	2	2	2	2	2	2
Q20	7	3	0	3	1	2	2	2	2	2	2	2
Q21	1	1	0	0	3	2	2	2	2	2	2	2
Q22	2	1	1	0	1	1	2	2	2	2	2	2
Q23	11	11	0	0	3	2	2	2	2	2	2	2
Q24	1	1	0	0	3	2	2	2	2	2	2	2
Q25	5	5	0	0	3	2	2	2	2	1	2	2
Q26	1	0	0	0	3	2	2	2	2	2	2	2
Q27	7	7	3	0	3	1	2	2	2	2	2	2
Q28	4	7	0	6	3	2	2	2	2	2	2	2
Q29	5	7	0	6	3	2	2	2	2	2	2	2
Q30	7	3	0	3	1	2	2	2	2	2	2	2
Q31	7	3	0	3	1	2	2	2	2	2	2	2
Q32	4	4	0	0	2	1	2	2	2	2	2	2
Q33	2	2	0	0	1	1	2	2	2	2	2	2
Q34	3	0	0	0	2	2	2	2	2	2	2	1
Q35	3	0	0	0	3	2	2	2	2	2	2	1
Q36	3	0	0	0	3	2	2	2	1	2	2	2

							Qtn 5	Qtn 7	Qtn 8	Qtn 9
	Freshmarket (F) or Juicing (J)	Average no. marketable carrots per plot *	% Packout	% diseased	% misshapen		Surface cover (1=clean, 2=bit trashy, 3=lot trashy)	Nematicides used on site? (1-yes:2-no)	Do you regularly use irrig. sched? (1-yes:2-no)	Tot irrig. used for crop (ML/ha)
T1	F	120.4	80.6	9.3	4.4	T 1	2	2	2	2.25
T2	F	61.5	83.7	0.0	11.9	T 2	1	2	2	2.50
T3	F	51.5	67.8	8.1	10.5	T 3	2	2	2	2.50
T4	F	84.3	74.8	7.6	6.5	T 4	2	2	1	n/a
T5	F	64.6	81.3	0.5	12.9	T 5	1	2	1	1.50
T6	F	79.0	74.1	6.6	4.6	T 6	2	2	1	1.07
T7	F	63.1	82.5	2.0	10.6	T 7	2	2	1	2.65
T8	F	44.0	83.8	0.0	5.6	T 8	1	2	2	n/a
T9	F	48.4	84.5	0.0	4.3	T 9	2	2	2	2.25
T10	F	73.3	44.5	32.9	10.9	T 10	2	2	2	1.90
T11	F	97.8	85.0	0.0	11.2	T 11	2	2	1	n/a
T12	F	56.1	93.5	0.0	2.5	T 12	1	2	2	2.00
T13	F	119.8	86.5	2.5	3.6	T 13	2	2	2	n/a
T14	F	62.0	74.1	3.2	14.6	T 14	2	2	2	2.75
T15	F	91.3	81.3	1.5	6.1	T 15	n/a	2	1	3.20
T16	F	55.9	79.3	1.2	15.3	T 16	1	2	2	n/a
T21	F	77.7	83.6	3.5	4.6	T21	2	2	2	6.00
T22	F	87.8	84.0	0.0	6.8	T22	1	2	1	2.65
T23	F	123.2	79.2	0.4	11.9	T23	2	2	2	4.00
T24	F	68.5	61.7	0.4	3.5	T24	1	2	2	4.50
T25	F	106.9	81.3	5.7	6.8	T25	2	2	2	1.75
T26	F	80.8	77.7	2.9	3.9	T26	2	2	1	1.50
T27	F	59.7	78.5	0.0	14.4	T27	3	2	2	2.50
T28	F	61.7	78.1	0.6	13.0	T28	2	2	2	3.50
T29	F	74.2	88.3	0.9	3.1	T29	1	2	2	2.00
T30	F	97.5	91.1	0.5	4.6	T30	2	2	1	2.15
T31	F	51.5	53.6	29.8	7.5	T31	1	2	2	n/a
T32	F	93.7	81.1	0.0	2.6	T32	2	2	1	n/a
T33	F	84.3	88.7	6.2	0.3	T33	2	2	2	n/a
T34	F	55.6	78.8	15.0	0.7	T34	1	2	2	5.00
T35	F	52.7	64.7	0.0	8.3	T35	2	2	2	5.00
T37	F	72.4	78.1	0.0	9.3	T37	2	2	2	2.70
T38	F	71.4	77.6	1.1	12.8	T38	2	2	2	1.00
T39	F	61.9	70.3	0.0	19.5	T39	2	2	2	n/a
T40	F	77.5	77.1	0.0	16.8	T40	2	2	1	3.50

Tasmania – carrot numbers adjusted for 6 plant rows, ie 3 double plant rows per bed

								Qtn 5	Qtn 7	Qtn 8	Qtn 9
	Freshmarket (F) or Juicing (J)	Av. wt of carrots per plot	Average no. marketable carrots per plot *	% Packout	% diseased	% misshapen		Surface cover (1=clean 2=bit trashy 3=lot trashy)	Nematicides used on site? (1-yes:2-no)	Do you regularly use irrig. sched? (1-yes:2-no)	Tot irrig. used for crop (ML/ha)
V2	J	3.7	62.7	100	N/A	N/A	**V2**	2	2	2	1ML
V3	J	8.9	107.3	100	N/A	N/A	**V3**	2	2	2	1ML
V4	J	9.6	107.7	100	N/A	N/A	**V4**	2	2	2	1ML
N1	J	9.4	121.3	100	N/A	N/A	**N1**	1	2	2	M
N2	J	6.7	96.0	100	N/A	N/A	**N2**				
N3	J	12.1	43.7	100	N/A	N/A	**N3**				
N5	J	13.0	74.0	100	N/A	N/A	**N5**	2	2	2	3.2ML
N6	J	6.8	34.3	100	N/A	N/A	**N6**	2	2	2	M
N7	J	8.8	77.7	100	N/A	N/A	**N7**	2	2	2	M

	Qtn 10	Qtn 13A	Qtn 13B	Qtn 15	Qtn 16	Qtn 17	Qtn 18	Qtn 19	Qtn 20	Qtn 21	Qtn 22	Qtn 23
	Deep cultivate? (1-yes:2-no)	Tot no. passes cultiv. equip for crop	Tot no. passes rotary hoe /power harrows	Erosion (0=none 1=severe 2=mod 3=little)	Tillage ease (Rating 0,1,2,3)	Cloddiness (Rating 0,1,2,3)	Surface crust (Rating 0,1,2,3)	To what extent is soil structure decline affecting the viability of your farming business? (Rating 0,1,2,3)	Infiltration (Rating 0,1,2,3)	Decomposition .(Rating 0,1,2,3)	Smell (Rating 0,1,2,3)	How many tones per ha of markt carrots do you estimate from the block we surveyed? (Rating 1,2,3,4)
V2	1	5	1	3	3	N/A	3	3	3	3	3	1
V3	1	5	1	3	3	N/A	3	3	3	3	3	1
V4	1	5	1	3	3	3	3	3	3	3	0	1
N1	1	4	1	0	3	3	2	2	3	2	0	1
N2												
N3												
N5	1	6	1	0	3	3	2	2	2	2	3	2
N6	1	5	0	3	1	1	1	2	1	M	2	2
N7	1	5	0	3	3	3	2	2	2	2	3	2

	Qtn 10	Qtn 13A	Qtn 13B	Qtn 15	Qtn 16	Qtn 17	Qtn 18	Qtn 19	Qtn 20	Qtn 21	Qtn 22	Qtn 23
	Deep cultivate? (1-yes:2-no)	Tot no. passes cultiv. equip for crop	Tot no. passes rotary hoe /power harrows	Erosion (0=none 1=severe 2=mod 3=little)	Tillage ease (Rating 0,1,2,3)	Cloddiness (Rating 0,1,2,3)	Surface crust (Rating 0,1,2,3)	To what extent is soil structure decline affecting the viability of your farming business? (Rating 0,1,2,3)	Infiltration (Rating 0,1,2,3)	Decomposition (Rating 0,1,2,3)	Smell (Rating 0,1,2,3)	How many tones per ha of markt carrots do you estimate from the block we surveyed? (Rating 1,2,3,4)
T 1	1	2	1	2	2	1	1	2	2	2	2	3
T 2	1	4	2	3	3	3	3	M	3	2	3	3
T 3	2	3	1	3	3	3	1	3	2	2	2	3
T 4	1	3	2	2	2	2	1	3	2	2	3	3
T 5	1	5	2	3	3	3	3	1	2	2	3	3
T 6	1	4	1	3	2	2	2	3	2	3	2	3
T 7	1	3	1	3	3	3	2	2	2	2	3	2
T 8	2	0	M	3	3	0	3	4	3	3	3	3
T 9	1	3	1	3	3	3	3	3	2	3	3	3
T 10	1	3	1	2	3	3	2	2	3	2	2	3
T 11	1	3	1	2	2	3	3	3	3	2	3	3
T 12	2	4	1	3	3	3	3	2	3	3	2	3
T 13	1	4	3	3	3	3	2	3	2	3	2	n/a
T 14	1	4	1	2	3	3	3	2	3	2	M	3
T 15	1	3	1	2	2	1	3	2	2	2	2	n/a
T 16	1	4	1	2	3	3	1	2	3	2	3	2
T21	1	4	2	2	3	3	3	2	3	3	3	3
T22	1	7	3	2	2	1	2	2	2	2	3	2
T23	1	5	3	3	3	1	2	3	0	3	2	3
T24	1	5	3	3	3	1	2	2	3	3	3	3
T25	1	4	2	3	3	1	3	3	3	2	2	n/a
T26	1	4	2	3	3	3	3	2	3	3	3	n/a
T27	2	n/a	n/a	3	3	3	2	2	2	2	2	2
T28	1	4	1	3	n/a	2	1	2	2	2	2	1
T29	1	6	1	3	3	3	2	2	2	3	3	3
T30	1	3	0	2	2	1	1	2	2	2	2	n/a
T31	1	3	1		3	3	3	3	3	3	2	3
T32	1	6	3	3	2	2	1	2	3	n/a	2	3
T33	1	4	2	2	2	3	1	3	2	3	2	3
T34	1	4	2	3	3	3	3	3	3	3	3	3
T35	1	3	1	2	3	3	3	3	3	3	n/a	3
T37	1	3	1	3	3	2	2	3	2	3	2	3
T38	1	4	2	3	3	3	3	3	3	3	3	3
T39	1	4	1	2	1	1	1	2	2	2	2	2
T40	1	2	0	3	3	2	2	2	3	2	2	3

	Qtn 24	Qtn 25A	Qtn 25B	Qtn 26	Qtn 27	Qtn 28	Qtn 29	Qtn 30	Qtn 31	Qtn 32	Qtn 33	Qtn 34	Qtn 35A	Qtn 35B
	Quality of produce (Rating 1,2,3,4)	Main cause of reduced pack-out (Rating 0,1,2,3,4)	Main cause of increased pack-out (Rating 0,1,2,3,4)	Crop appearance (Rating 0,1,2,3,4)	Nutrient deficiency (Rating 0,1,2,3,4)	Plant density (Rating 0,1,2,3,4)	Growth rate (Rating 0,1,2,3,4)	Roots (Rating 0,1,2,3,4)	Foliage (Rating 0,1,2,3,4)	Resists drought (Rating 0,1,2,3,4)	Resists pests and disease (Rating 0,1,2,3,4)	Weed pressure (Rating 0,1,2,3,4)	No. weed species present	Was nut grass the major weed present? (Rating 1-yes:2-no)
T 1	2	0	n/a	4	4	4	4	4	4	4	4	3	2	2
T 2	2	5,4	n/a	4	4	4	4	4	4	4	4	4	0	2
T 3	2	5	n/a	2	3	3	2	3	2	3	3	1	1	2
T 4	2	5,4	n/a	4	4	4	3	4	4	4	4	2	2	2
T 5	2	5	n/a	4	4	4	4	4	4	4	4	3	1	2
T 6	2	2,4,5	n/a	3	3	4	3	4	3	4	3	3	2	2
T 7	3	5	n/a	3	4	4	4	3	4	4	4	2	4	2
T 8	2	3	n/a	4	4	4	4	4	3	3	4	4	0	2
T 9	3	4	n/a	3	4	3	3	3	3	4	4	4	0	2
T 10	2	4	n/a	3	4	3	3	4	4	4	4	4	0	2
T 11	2	3,5	n/a	3	4	4	4	4	3	4	4	3	2	2
T 12	1	5	n/a	3	4	4	4	4	4	4	4	4	0	2
T 13	2	5	n/a	3	3	3	4	4	3	3	4	2	2	2
T 14	2	5	n/a	3	4	3	3	4	3	4	4	3	1	2
T 15	2	5	n/a	3	3	3	3	3	3	3	3	2	3	2
T 16	2	5,3	n/a	4	4	4	4	4	4	4	4	2	2	2
T21	n/a	n/a	n/a	4	4	4	4	4	4	4	4	3	1	2
T22	2	5,3	n/a	4	4	4	4	4	4	4	4	4	0	2
T23	1	3	n/a	4	4	3	3	3	4	3	4	3	3	2
T24	1	3	n/a	3	4	4	4	3	3	4	3	3	3	2
T25	n/a	n/a	n/a	2	2	2	2	3	2	3	2	2	3	2
T26	n/a	4	n/a	4	4	4	4	4	4	4	4	2	1	2
T27	n/a	1,3	n/a	3	3	3	3	3	3	3	3	1	1	2
T28	2	n/a	n/a	3	4	4	4	4	4	4	4	3	2	2
T29	2	n/a	n/a	4	4	4	4	4	4	4	4	3	0	2
T30	n/a	n/a	n/a	4	4	4	4	4	4	4	4	3	1	2
T31	1	4,3	n/a	4	4	4	4	4	4	4	4	4	0	2
T32	3	1	n/a	3	3	2	3	3	3	2	4	2	2	2
T33	2	4,5	n/a	4	4	4	4	4	4	4	3	2	0	2
T34	2	3	n/a	4	4	4	4	4	4	4	4	4	0	2
T35	1	5	n/a	3	3	4	3	3	3	3	4	3	3	2
T37	3	n/a	n/a	4	4	3	3	3	4	4	4	3	0	2
T38	1	5,3	n/a	4	4	4	3	4	3	3	3	3	3	2
T39	1	5	n/a	4	4	4	4	4	4	4	4	2	3	2
T40	2	n/a		2	3	4	2	2	3	4	4	1	6	0

	Qtn 24	Qtn 25A	Qtn 25B	Qtn 26	Qtn 27	Qtn 28	Qtn 29	Qtn 30	Qtn 31	Qtn 32	Qtn 33	Qtn 34	Qtn 35A	Qtn 35B
	Quality of produce (Rating 1,2,3,4)	Main cause of reduced pack-out (Rating 0,1,2,3,4)	Main cause of increased pack-out (Rating 0,1,2,3,4)	Crop appearance (Rating 0,1,2,3,4)	Nutrient deficiency (Rating 0,1,2,3,4)	Plant density (Rating 0,1,2,3,4)	Growth rate (Rating 0,1,2,3,4)	Roots (Rating 0,1,2,3,4)	Foliage (Rating 0,1,2,3,4)	Resists drought (Rating 0,1,2,3,4)	Resists pests and disease (Rating 0,1,2,3,4)	Weed pressure (Rating 0,1,2,3,4)	No. weed species present	Was nut grass the major weed present? (Rating 1-yes:2-no)
V2	2	3	N/a	2	3	2	2	2.5	3	0	0	3	3	2
V3	2	3	N/a	3.5	4	4	3.5	4	4	0	0	3	3	2
V4	3	3	N/a	3	4	4	N/a	4	3	N/a	N/a	3	2	2
N1	N/a	1,4	0	4	4	3	3.5	3.5	4	3	4	4	2	2
N2														
N3														
N5	2	1,4	0	4	4	3	3	3	3	3	3	4	2	2
N6	N/a	0	0	4	3	2	3	1	3	M	3	3	M	M
N7	N/a	0	0	4	3	3	3	3	4	M	3	4	M	M

	Qtn 1A	Qtn 1B.	Qtn 1C.	Qtn 1D	Qtn 3	Qtn 6A	Qtn 6B.	Qtn 6C.	Qtn 14A.	Qtn 14B.	Qtn 14C.	Qtn 14D.
	Total No. vegetable crops planted within the last 5 years	No. times Fumigant used on site within past 5 years	No. times site fallowed in past 5 years	No. times a green manure crop grown in past 5 years	Over last 5 years has yield increased, decreased, stayed the same? (Rating 1,2,3)	Has use of fertiliser increased in past 5 years? (Rating 1-yes:2-no)	Has use of soil fumigation increased in past 5 years? (Rating 1-yes:2-no)	Has use of nematicides increased in past 5 years? (Rating 1-yes:2-no)	Has ploughing become more difficult in past 5 years? (Rating 1-yes:2-no)	Are more dense clods being brought to the surface than previously within last 5 years? (Rating 1-yes:2-no)	Is there increased incidence of sealing or waterlogging? (Rating 1-yes:2-no)	Is water infiiltration rate decreasing? (Rating 1-yes:2-no)
T 1	0	0		0	3	2	2	2	2	1	2	2
T 2	n/a	0		0	3	2	2	2	2	2	2	2
T 3	2	0	1	0	3	2	2	2	2	2	1	2
T 4	1	0		0	3	2	2	2	2	2	2	2
T 5	4	0	2	0	M	1	2	2	2	1	2	2
T 6	1	0	4	0	3	2	2	2	2	2	2	2
T 7	4	0		0	3	2	2	2	2	2	2	2
T 8	4	0	3	0	3	2	2	2	2	2	2	2
T 9	6	0		0	1	2	2	2	2	2	2	1
T 10	6	1		0	1	2	2	2	2	2	2	1
T 11	1	0		0	3	2	2	2	2	2	2	2
T 12	3	0		0	3	2	2	2	2	2	2	2
T 13	2	0		0	3	2	2	2	2	2	2	2
T 14	0	0		0	M	2	2	2	2	2	2	2
T 15	2	0		0	3	2	2	2	2	1	2	1
T 16	3	0		0	1	1	2	2	2	2	2	2

	Qtn 1A	Qtn 1B.	Qtn 1C.	Qtn 1D	Qtn 3	Qtn 6A	Qtn 6B.	Qtn 6C.	Qtn 14A.	Qtn 14B.	Qtn 14C.	Qtn 14D.
	Total NO. vegetable crops planted within the last 5 years	No. times Fumigant used on site within past 5 years	No. times site fallowed in past 5 years	No. times a green manure crop grown in past 5 years	Over last 5 years has yield increased, decreased, stayed the same? (Rating 1,2,3)	Has use of fertiliser increased in past 5 years? (Rating 1-yes:2-no)	Has use of soil fumigation increased in past 5 years? (Rating 1-yes:2-no)	Has use of nematicides increased in past 5 years? (Rating 1-yes:2-no)	Has ploughing become more difficult in past 5 years? (Rating 1-yes:2-no)	Are more dense clods being brought to the surface than previously within last 5 years? (Rating 1-yes:2-no)	Is there increased incidence of sealing or waterlogging? (Rating 1-yes:2-no)	Is water infiiltration rate decreasing? (Rating 1-yes:2-no)
T21	3	0	3	3	3	2	2	2	2	2	2	2
T22	8	0	0	1	1	1	2	1	1	1	1	1
T23	2	0	4	4	3	2	2	2	2	2	2	2
T24	4	0	2	2	2	2	2	2	2	2	2	2
T25	2	0	0	1	3	2	2	2	2	1	2	2
T26	7	0	0	0	2	2	2	2	n/a	n/a	n/a	n/a
T27	1	0	0	0	2	2	2	2	n/a	n/a	n/a	n/a
T28	3	0	0	0	3	2	2	2	2	2	2	1
T29	4	0	2	2	3	1	2	2	n/a	n/a	n/a	n/a
T30	3	0	0	0	3	2	2	2	1	1	2	2
T31	8	0	0	0	3	2	2	2	1	2	2	2
T32	4	0	0	0	1	1	2	2	2	1	2	2
T33	2	0	1	0	3	2	2	2	2	2	1	2
T34	3	0	2	0	3	2	2	2	2	2	2	2
T35	5	0	0	0	3	2	2	2	2	2	2	2
T37	1	0	0	0	n/a	2	2	2	2	2	2	2
T38	2	0	3	2	3	1	2	2	2	2	2	2
T39	4	0	0	0	1	2	2	2	2	1	2	2
T40	0	0	n/a	0	1	1	2	2	2	2	2	2
V1												
V2	3	1	3	0	3	2	2	2	2	2	2	2
V3	3	1	3	0	3	2	2	2	2	2	2	2
V4	4	0	N/A	0	3	2	2	2	2	2	2	2
N1	3	0	0	0	2	2	2	2	2	2	2	2
N2												
N3												
N5	3	0	2	0	3	1	2	2	2	2	2	2
N6	4	0	2	0	2	1	2	2	1	1	2	2
N7	5	0	1	0	2	1	2	2	2	2	2	2