Benchmarking Uptake of Soil Health Practices

Dr Gordon Rogers
Applied Horticultural Research P/L

Project Number: VG11034

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Benchmarking Uptake of Soil Health Practices

Gordon Rogers

Applied Horticultural Research

Horticulture Australia
Project Number: VG11034

September 2012

Project Leader: Gordon Rogers
Applied Horticultural Research
P.O. Box 3114
Bundeena NSW 2230

Key Personnel:
Mike Titley - AHR
Lynn Christie - AHR
Matthew Hall - AHR

Funding

This project has been funded by HAL using levy funds from the Australian vegetable industry and matched funds from the Australian Government.

The broad objective of this project was to review the HAL soil health program, undertake a survey of Australian vegetable growers to assess uptake of the outcomes of soil health research and to recommend new areas for investment.

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1 Media summary

In 2006/07, Horticulture Australia Limited (HAL) identified soil health as a priority for the vegetable industry. This followed concerns being raised that poor management of soil health could result in large losses to productivity, increased disease and long-term damage to catchments.

Subsequently, a vegetable industry soil health program was implemented, comprising three individual projects. Two were funded through HAL using vegetable levy funds; one focused on tropical vegetable production, the other on temperate vegetable production. The third, a ute guide to soil management, was funded by the Australian Government through the Healthy Soils for Sustainable Farms program.

This current project, Benchmarking Uptake of Soil Health Practices, was commissioned to review the soil health program, survey vegetable growers on their uptake of the program outputs and soil health management skills, and to recommend future directions for soil research in the Australian vegetable industry.

The main findings from the project reviews and vegetable grower survey include:

- There is strong support for the soil health program among growers.
- Smaller, regional projects are preferred, which effectively communicate outcomes relating to soil health, productivity and economics that fit specific local production systems.
- National coordination of soil research, soil assessment protocols and a repository of soil research information is needed.
- There is a need for closer linkages with broader soil research, development and extension (RD&E).
- Traditional soil cultivation methods are still widely used.
- There are high adoption rates of: green manure crops (incorporated); composted manures and biological activators; and soil testing.
- Adequate general reference information on vegetable soil management is available but a lack of specific information is hindering improvement.
- Skills deficiencies were identified among consultants and growers, including in the areas of: soil biology and microorganisms; soil-borne disease control; interpretation of soil test results; biofumigation and alternatives to metham sodium; and fertilizers and nutrition.
- RD&E priority issues were identified as: soil-borne diseases; biofumigation; nutrition; soil biology; and controlled traffic/minimum tillage to reduce input costs and improve soils.

2 Technical summary

In 2006/07, Horticulture Australia Limited (HAL) identified soil health as a priority for the vegetable industry. This followed concerns being raised that poor management of soil health could result in large losses to productivity, increased disease and long-term damage to catchments. Four key areas of research, development and extension were deemed necessary to address soil health issues. These were:

- Benchmarking crop health, quality, yields and profit.
- Improved management of soil erosion through improved tillage and management of organic matter.
- Good soil health practices to improve water-use efficiency.
- Benefits of good soil health management on climate change.

Subsequently, a vegetable industry soil health program was implemented, comprising three individual projects. Two were funded through HAL using vegetable levy funds. The third was funded by the Australian Government through the Healthy Soils for Sustainable Farms program.
The projects were:

1. Vegetable plant and soil health (VG06100)
2. Benchmarking soil health for improved crop health, quality, and yields in the temperate Australian vegetable industries (VG07008)
3. Healthy Soils for Sustainable Vegetable Farms: Ute Guide & Soil Health Interpretation Courses for Vegetable Growers

This current project, Benchmarking Uptake of Soil Health Practices, was commissioned to review the soil health program, survey vegetable growers on their uptake of the program outputs and soil health management skills, and to recommend future directions for soil research in the Australian vegetable industry.

The main findings from the project reviews and vegetable survey were:

- There is strong engagement with the soil health program by growers and support for soils research to continue.

- Smaller, regional projects are preferred to large, all-encompassing projects.

- Projects should develop outcomes that fit production systems, with impacts on soil health, productivity and economics communicated effectively to growers.

- National coordination of soil research, soil assessment protocols and a repository of soil research information is needed.

- Closer linkages with broader soil research, development and extension (RD&E) programs are proposed.

- Growers understand soil texture (soil type), structure, pH, nutrients and soil organic matter but have limited understanding of subsoils, cation exchange capacity/nutrient-holding capacity and soil biology.

- Traditional soil cultivation methods are still widely used.

- There are high adoption rates of: green manure crops (incorporated); composted manures and biological activators; and soil testing. Growers are willing to change soil management practices if they are effective.

- 98% of growers use soil testing and of these, 93% maintain paper records. Only 43% of growers also store soil test results electronically in a retrievable form (database or spreadsheet).

- Adequate general reference information is now available on soil management for vegetable growers.

- A lack of good, specific information is hindering improvement in soil management. Skills deficiencies were identified among consultants and growers, including in the areas of: soil biology and microorganisms; soil-borne disease control; interpretation of soil test results; biofumigation and alternatives to metham sodium; and fertilizers and nutrition.

- Australian vegetable growers identified the following RD&E issues, in order of priority:

    1. Soil-borne diseases.
    2. Biofumigation.
    3. Nutrition, especially in relation to organic composts.
    4. Soil biology – organic supplements and microbial activators.
    5. Controlled traffic and no-till to reduce input costs and improve soils.
    6. Soil health – general.
    7. Organic composts and green manure crops, which are being widely used.

3 Introduction

In 2006/07 Horticulture Australia Limited (HAL) identified soil health as a priority for the vegetable industry. This followed concerns being raised that poor management of soil health could result in large losses to productivity, increased disease, and long-term damage to catchments.

Project VG06090 (Management of soil health for sustainable vegetable production), delivered by the Department of Primary Industries, Victoria, was funded by HAL to conduct a 12-month review to assist HAL and the vegetable industry to develop a strategic direction for soil health research and development (R&D). A literature review was completed and workshops held throughout Australia to identify the priority soil health issues for R&D investment. Four key priorities were identified. These were; benchmarking crop health, quality, yields and profit; improved management of soil erosion through improved tillage and management of organic matter; good soil health practices to improve water use efficiency; and benefits of good soil health management on climate change.

Importantly, the key drivers to adopt good soil health management to improve yields, profit and product quality were identified at the workshops as being: More effective management of inputs (water, pesticides, fertilisers, organics); improvements to soil structure and water use efficiency; and sustainable disease control.

Subsequently, a vegetable industry soil health program was implemented, comprising three individual projects. Two were funded through HAL using vegetable levy funds; one focussed on tropical vegetable production and the other on temperate vegetable production. The third was funded by the Australian Government through the Healthy Soils for Sustainable Farms program.

- Vegetable plant and soil health (VG06100)
- Benchmarking soil health for improved crop health, quality, and yields in the temperate Australian vegetable industries (VG07008)
- Healthy Soils for Sustainable Vegetable Farms: Ute Guide & Soil Health Interpretation Courses for Vegetable Growers

The scope of this project (VG11034 Benchmarking Uptake of Soil Health Practices) is to:

- Review completed soil health project reports.
- Design soil health adoption & benchmarking study.
- Conduct survey of growers in major growing regions.
- Generation of benchmark results.
- Preparation of a project final report.

Face-to-face survey work was undertaken in: Queensland (North Queensland, Lockyer Valley); Victoria (Cranbourne and Werribee); Tasmania (Devonport/Launceston); Western Australia (Perth region and Bunbury); and the Sydney region (Camden, Richmond). Additionally, phone interviews were held with growers in other regions. In particular, regions where soil workshops were held as part of the ute guide project were targeted (e.g. Camden [Sydney], Dareton/Mildura, Virginia, and Darwin).

The primary project output is a final report containing the results of the information gathered from the major growing regions across Australia. Within the final report the following points are addressed:

- What the soil health program achieved from a scientific output.
- What has been taken up by industry. What failed and why.
- From the results of (1) and (2) a set of guidelines has been formulated for future projects of this nature. This may also have wider relevance for soil health and vegetable production across Australia.
- These guidelines also will be used to formulate generic KPIs that will need to be built in as part of the milestones for future projects.

3.1 Resources that have been produced in association with various soil health projects

1. **VG07008 outputs**
    a. Soil health management chart
    b. Improving soil health for yielding profit in vegetables: soil health management guide
    c. Vegenotes Issue 18 2010: Water use efficiency/Benchmarking soil health for improved soil health and yields
    d. 5 Victorian DPI information leaflets:
        i. Soil Biota and SOM
        ii. Modelling SOM
        iii. Non-living SOM Fractions
        iv. SOM and the Carbon Cycle
        v. SOM and Nutrient Cycling

2. **Ute guide outputs**
    a. The Ute Guide handbook
    b. Healthy Soils Awareness Day workshop fliers
    c. Smart Choice newsletter April 2009
    d. Soil Awareness Day notes

3. **VG06100 Outputs**
    a. VegPASH Newsletters June 2007, November 2007, July 2008 and February 2009
    b. Vegenotes Issue 12 2009: Indicators of soil health
    c. Soil health manual (QDAFF)

4. **Other outputs**
    a. Vegenotes Issue 7 2008: Healthy soil management.
    b. VG99057: Sustainable soil health for intensive production.
    c. QDAFF 2010: Soil health for vegetable production in Australia.
    d. Acid Soil Action Leaflet NSW DPI Leaflet No. 3: Are my soils acid?
    e. Diagnosing and ameliorating problem soils: decision tree on how to diagnose and ameliorate problem soils (WA Department of Agriculture).
    f. Optimum soil pH for crop plants (WA Department of Agriculture).
    g. TL00034 – Preparing soil for vegetable crops: Soil organic matter and pH.
    h. Testing soils for residues of persistent chemicals (NSW DPI Primefact 320).
    i. VN00001 – Soil Moisture Monitoring (no doc).
    j. Soil Management – Vegetables WA.
    k. Vegetable Industry Development Program – Soil Health.

Funding in soil health continues with the HAL funded project: Vegetable soil health systems for overcoming limitations causing soil-borne diseases (VG09038). The project is based in northern Queensland and will be completed in 2013.

Additionally, soil health projects and fact sheets have been funded by HAL and the vegetable industry prior to the establishment of the soil health program:

1. VG99057 - A survey approach to investigate the soil factors associated with the productivity and sustainability of vegetable production in Australia.
2. VX99043 - Enhancing root and soil health in tomato and melon cropping systems.

Key outputs of the soil health program to-date, as identified by HAL include:

1. Knowledge and extension tools that improve management of organic carbon and tillage practices on-farm to improve water-use efficiency, disease control, nutrient use efficiency and soil structure, and extension of the information to drive adoption of the best practice soil health management.

2. Knowledge of the impact of common inputs (e.g. pesticides, fertilisers, tillage practices and water use) into vegetable cropping through temperate Australia and the impact on growers' bottom line (i.e. crop production and profit on farm).

3. Better understanding of the biological, chemical and physical tests that can be used to benchmark healthy soils for vegetable production systems.

3.2 What is soil health?

Soil health encompasses the physical, chemical and biological attributes of a soil, all of which are inter-related. If any soil attribute is limiting it can impact other soil attributes, and the soil will perform below its potential. This in turn will negatively impact product quality and yield, and profitability through production losses and increased input requirements. Off-farm environmental damage may also occur.

Some definitions of soil health are:

> "A healthy soil is a soil that is productive and easy to manage under the intended land use. It has biological, physical and chemical properties that promote the health of plants, animals and humans while also maintaining environmental quality." Australian Government Soil Health Knowledge Bank (www.soilhealthknowledge.com.au)
>
> "Soil health is the product or outcome of the functioning of the soil system for a given purpose....Good soil health management takes a holistic view of how we can create a soil environment where the physical, chemical and biological components work together to sustain plant growth with minimal impact on the surrounding environment." What is a Healthy Soil? (http://www2.dpi.qld.gov.au/extra/pdf/hort/healthysoil.pdf)
>
> "This manual takes a holistic view of soil heath by considering the interaction of physical, chemical and biological soil properties. The balance and stability of these components are what make a healthy soil." Soil Health for Vegetable Production in Australia (http://www.daff.qld.gov.au/documents/PlantIndustries_FruitAndVegetables/Soil-health-vegetable-production.pdf)
>
> Soil health has been defined as: "the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production". To that definition, an ecosystem perspective can be added: A healthy soil does not pollute the environment; rather, it contributes to mitigating climate change by maintaining or increasing its carbon content." Food and Agriculture Organisation (FAO) of the United Nations (http://www.fao.org/ag/save-and-grow/en/3/index.html)

4 Review completed soil health projects

This section of the report reviews the three main projects which formed the basis of the HAL soil health program:

- Benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries (VG07008)
- Vegetable Plant and Soil Health (VG06100)
- Healthy Soils for Sustainable Vegetable Farms: Ute Guide & Soil Health Interpretation Courses for Vegetable Growers

Other soil health research relevant to the Australian vegetable industry has been summarised.

4.1 Benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries (VG07008)

4.1.1 Summary

Project VG07008 was funded by HAL using the vegetable levy and matched funds from the Australian Government. State Government funding was also provided through the Department of Primary Industries, Victoria. It was completed in December 2010.
The Project Leader was Dr Ian Porter (Department of Primary Industries, Victoria), with team members also from DPI Victoria.

This project, in response to the outcomes of VG06090, aimed to identify the cost/benefits that could be gained by investment in soil health research. In particular, what benefits would the vegetable industry gain by using more sustainable cropping practices for yield and disease control, and what benefits could be derived from more efficient fertiliser use and reduced water inputs.

4.1.2 Scope and objectives

In response to the need to find alternative methods to pesticides to manage soil-borne diseases in vegetable crops and the desire by growers to find better ways of managing soil health for more sustainable cropping production, this project aimed to:

- Investigate the effects of common soil management practices on soil health and crop productivity in the vegetable industry.

- Examine the physical, chemical and biological changes in soil after different treatments are applied to identify cropping practices which improve soil health.

- Determine the potential cost/benefit of several key organic and inorganic amendments used throughout the vegetable industry by measuring the response of crops after treatment.

4.1.3 Project team

Ian J. Porter, Scott Mattner, Jacqueline Edwards, Robyn Brett, David Riches, Christina Hall, Belen Guijarro, Masha Fridman (Department of Primary Industries, Victoria: Biosciences)
Peter Fisher, Nick O'Halloran, Siegfried Engleitner, Debra Partington (Department of Primary Industries, Victoria: Future Farming Systems).

4.1.4 Technical content of the study

The project comprised five main parts. These were:

- Benchmarking soil health indicators for temperate vegetable production in Australia.
- Influence of soil health practices on soil-borne pathogens and diseases of vegetables under controlled conditions.
- A series of 6 groups of field trials in Victoria and Tasmania aimed at determining the effect of common farming practices on soil health.

- The effect of various organic additives on soil carbon, soil water and fertility, and implications for nitrogen requirements for broccoli grown on sandy soils.
- Long-term effects of continuous vegetable cropping on the physical and chemical properties of a sandy soil.

The project also had a strong extension and communication component.

1. Benchmarking studies

Benchmarking studies included taking soil samples at 37 sites in southern Australia. This was to obtain further baseline data of the effect of sustainable practices on soil quality parameters indicating better soil health. The methodology was based on the Cornell Soil health evaluation model and the testing included:

- Physical properties (penetrometer, aggregate stability and water infiltration rate).
- Chemical properties (C, N, OM, EC; pH; exchangeable cations [Ca, Mg, K, Na, sum of four cations, Ca:Mg, total soluble salts]; plant available nutrients [ammonium-N, nitrate-N, P (Olsen), K, Cu, Fe, Mn, Zn]).
- Biological properties (microbial biomass [FDA]; fungi:bacteria ratio; soil respiration; labile carbon and nematode population studies).

Only top 15cm layer of soil tested.

2. Influence of soil health practices on soil-borne pathogens and diseases of vegetables under controlled conditions.

This aspect of the project is outside the scope of this review and will be covered by a separate project.

3. A series of 6 groups of field trials in Victoria and Tasmania aimed at determining the effect of common farming practices on soil health.

Six short-term and two long-term field trials were conducted on commercial vegetable farms in Victoria and Tasmania to determine the impact of common farm practices used throughout the Australian vegetable industry on soil health, crop productivity and grower profits. These trials also assessed which soil health indicators best measured the physical, chemical and biological changes that occur with different practices.

The short-term Victorian trials examined the effects of nitrogen form and nitrification inhibitors, fumigants, fungicides, fertilisers and composts on crop yield and soil characteristics. A short-term trial in Tasmania examined the effects of green waste and paper sludge organic amendments on production and soil properties. Treated soil samples from some of these trials were also assessed for disease suppression.

Two long-term trials were carried out to evaluate the effects of more sustainable cropping practices. One long-term trial in Boneo, Victoria evaluated three organic amendments and metham sodium fumigation on the yield and profitability of broccoli, soil microbial populations and soil carbon over 3 years.

The second long-term study at Devon Meadows in Victoria evaluated organic amendments including those with a biofumigant action in combination with crop rotations (rye corn) on soil biological activity, soil-borne disease and crop productivity. A large amount of data was collected from this study, including changes in soil carbon, organic matter, biological activity, crop yield and disease monitored over a three-year period. More than 25 soil physical, biological and chemical parameters were also recorded.

4. The effect of various organic additives on soil carbon, soil water and fertility, and implications for nitrogen requirements for broccoli grown on sandy soils.

The effect of amendments with differing C:N ratios (Pinegro compost, chicken manure, silage and lignite) commonly used to increase soil carbon were compared with standard grower practice on soil carbon, soil water and fertility. Impacts on soil organic matter, soil C:N ratio, soil fertility and nitrogen availability, plant-available water and yield were evaluated.

5. Long-term effects of continuous vegetable cropping on the physical and chemical properties of a sandy soil.

The impact of continuous vegetable farming on a sandy soil involving practices that supply high levels of organic matter to the soil such as: retaining crop residues, growing green manure crops and applying chicken manure were evaluated over a seven-year period. A number of key soil health characteristics (e.g. total organic C. salinity, nutrient levels, water infiltration and bulk density) were assessed after one, three and seven years of vegetable production. Two soil depths were evaluated, 0–10 cm and 10–30 cm. A particular focus of this study was the long-term effects of vegetable cropping on soil organic carbon and total nitrogen. In addition, an extension tool known as Res-Cal, for calculating the quality of organic carbon being returned to the soil, was evaluated.

4.1.5 Key research findings from the project

Benchmarking study

- Data collected from 37 benchmarking studies showed that nutrient inputs in Australian vegetable production are largely matched to the crops requirements with the exception of phosphorus and sulphur which generally were well in excess of crop requirements.

- Phosphorus levels in vegetable-growing soils were generally well in excess of crop requirements with 70% of sites having high to excess levels. A subsequent trial conducted on a major commercial property showed that fertiliser input could be reduced by up to 50% without affecting yields.

- Results for nitrate and potassium showed changes over the cropping cycle but could not be attributed to crop uptake, leaching or loss of N2O. More data would be needed to identify these losses.

- The soil indicators were able to give limited discrimination (within sample) for soil type. However, the soil indicators were not able to discriminate between management practices (carbon amendments, organic production and conventional production) or between fumigated and non-fumigated soils, both of which had less balanced sample distributions across categories.

- This pilot study has identified soil indicators that differ between soil types and management practices. These indicators and other soil parameters that have known acceptable ranges (e.g. pH, EC, phosphorous, sulphur etc) were useful for assessment of soil health.

- The results suggest that measurement of these physical, chemical and biological tests should continue in future projects and that these results should be coordinated into a national database that would be of great benefit to the industry.

Short-term trials

- The short-term trials demonstrated that growers can improve yields and profitability up to $6000/ha with better-managed nutrient applications. The slow-release nitrogen fertilizer, Alzon®, gave significant yield and profit returns in both autumn and summer, and is expected to be beneficial to soil health.

- Nitrification inhibitors reduce the potential for nitrate pollution of waterways and groundwater and therefore are assumed more beneficial to soil health and the environment.

- Composted green organic waste, composted chicken manure and biofumigants (e.g. Fumifert), produced equivalent or higher yields than standard grower practice or fumigation. The yield response and profitability generally were greater in summer than autumn, probably due to the shorter cropping period and higher release rates of available nutrients.

- On sandy soils, short-term application of organic amendments was shown to provide small increases in soil carbon and organic matter.

- The treatments used in the short-term trials generally provided only transient effects in biological activity and therefore long-term disease suppression due to shifts in microbial populations would be unlikely. This is in contrast to the longer-term trials where high levels of organic inputs were repeated into the same soils over three seasons.

- Organic treatments tended to decrease pH and this confirms the findings of previous studies. This is important for brassica production where clubroot disease is a problem, as growers may need to lime soils where organic products are applied, to avoid promoting disease.

Long-tem trials

1. <u>Organic additives over 3 years on sandy soil in southern Australia</u>

- Organic amendments can be effective in significantly increasing the amount of organic carbon in the soil. However, the response in TOC is dependent on the chemical composition of the organic amendment applied.

- Organic amendments with a lower C:N ratio and more labile forms of carbon (e.g. chicken manure) increased soil organic carbon levels in the short term, but could not be maintained with smaller subsequent applications. Lignite, which had the highest C:N ratio and was the least labile of organic amendments applied, maintained significantly higher TOC levels with smaller applications.

- Pinegro compost and composted chicken manure had the lowest C:N ratio of the organic amendments used, and consequently were the only organic amendments able to significantly increase organic nitrogen fertility in this experiment.

- Lignite supplied the least organic nitrogen and consequently significantly increased the C:N ratio of the soil. This is likely to reduce nitrogen fertility and potentially increase nitrogen immobilisations.

- The application of compost, chicken manure and lignite all significantly increased the water-holding capacity of the soil, but had no impact on plant-available water content.

- The application of all the organic amendments, except lignite, resulted in broccoli yields that were statistically equal or greater compared to the standard grower practice, while using only half the rate of nitrogen fertiliser. With the exception of chicken manure, yield was further improved by the combination of organic amendments and full nitrogen fertiliser rates.

2. Long-term effects of continuous vegetable cropping (8 years)

- Longer-term vegetable production reduced soil carbon levels despite high organic matter inputs. On average this was equivalent to 0.2% less total organic carbon (TOC) (0–30 cm depth) per year.

- The long-term, lightly grazed pasture in the zero-year paddock demonstrated that high levels of TOC can be established even in sandy soils under a suitable farming system.

- Phosphorous and copper were higher in the paddocks that had been in vegetable production for longer.

- The other soil fertility parameters of organic nitrogen, nitrate, potassium, sulphur and iron, as well as electrical conductivity, all showed a pattern of declining with time. This is likely to increase reliance on inorganic fertilisers or organic inputs to meet crop nutrient requirements.

- The major tillage that occurs before each crop is likely to conceal changes in soil health parameters, especially soil physical properties.

4.1.6 Project outputs and outcomes

There were a large number of important findings from the project, and these have been summarised in the preceding sections. However, the most important findings and outcomes, and those of greatest value to the Australian vegetable industry, can be summarised as follows:

1. An increase in crop productivity (up to 15%) and profits (up to $3,000/ha) are possible through better management of crop nutrition (e.g. use of nitrification inhibitors and matching nutrient supply to crop requirement).

2. Grower surveys, which assisted the direction of the project, showed that 75% of growers were over-fertilizing vegetable crops and that large amounts (possibly 80%) of this fertilizer was wasted. Part of the large response with the stabilized (nitrification inhibited) fertilizers could be explained by better nitrogen-use efficiency.

3. A major study within the project showed that continuous cropping in the intensive vegetable production systems in Victoria can lead to a reduction of 66% of the soil carbon over a short period compared to other practices such as pasture.

4. There is great potential for existing organic amendments such as poultry manure, composted green waste and biofumigant crops to be applied differently from the present practices to increase crops yields by up to 10% and suppress soil-borne diseases. For example, if used properly, yield losses to disease could be decreased by 20% due to the disease-suppressive effects of some organic matter amendments in soil.

5. There was an acidifying effect of some organic supplements, which may or may not increase the incidence of soil-borne diseases. In the trials conducted, all amendments except silage increased club root, and this will need practices developed to ensure products are used correctly, e.g. by applying appropriate amounts of lime to increase soil pH.

6. Water infiltration could be improved by 30% with the addition of organic matter to the soil surface as a mulch.

7. In the highly-tilled systems trialled, organic supplements provided immediate benefits to soil health, plant yields and profits by increasing soil microbial activity, but, other than lignite, did not result in higher long-term total organic carbon (TOC) levels in vegetable soils. This will be important for growers who are seeking carbon offsets under the Carbon Farming Initiative and suggests reducing tillage in the highly-intensive systems in southern Australia is more likely to build soil carbon that OM additions per se.

8. A user-friendly computer-based tool (C-Calc) was developed to help estimate the amount of organic matter returned to soil, and six leaflets were produced to provide information about better use of organic matter for crop yield.

9. A suite of soil health tests based on the Cornell model were developed and tested. These allow growers to accurately measure physical, chemical and biological changes in soil quality and consequently measure changes in soil health.

10. This project was part of a nationally coordinated strategic plan set up in consultation with growers to reduce input costs, improve soil health and increase productivity. The project leader claims significant uptake of improved practices within 2 years of the completion of the project. This will be addressed by the grower survey.

(i) Scientific outputs

O'Halloran, N. et al. (2011) Organic amendments necessitate a trade-off between building soil organic carbon and supplying crop nitrogen. Acta Hort. (submitted)

Porter, I.J. et al. (2011). Influence of soil organic matter on soil health, crop productivity and N2O emissions in vegetable crops. Acta Hort. (submitted)

O'Halloran, N.; Fisher, P.; Aumann, C.; et al. (2010) Relationship between organic matter retention and soil carbon in irrigated mixed farming systems. Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010.

Assessment of a user-friendly computer-based tool ('C-Calc') to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.

13 additional conference papers.

Honours Thesis: Hanlon, L.M. (2010). Club root expression in brassica crops in an organically amended horticultural soil. Honours thesis. University of Melbourne.

(ii) Communication / extension activities and outputs

- 28 grower seminars and workshops conducted.
- 14 national conference presentations.
- 3 radio interviews.
- 3 articles in Vegetables Australia magazine.
- Soil health management chart: benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries distributed to more than 300 growers at workshops.
- Improving soil health for yield and profit in vegetables: soil health management guide.
- Veggie notes issue 18.
- Five Victorian DPI information leaflets:
    - Soil Biota and SOM
    - Modelling SOM
    - Non-living SOM Fractions
    - SOM and the Carbon Cycle
    - SOM and Nutrient Cycling

(iii) Geographical coverage within the Australian vegetable industry

- Soil samples were taken at 37 sites in southern Australia in the following regions: Bairnsdale; SE Melbourne; Yanco (NSW); Valla (NSW); Tasmania; and Boneo. Field trials were conducted in Victoria and Tasmania.

- Field trials were conducted over several sites in Victoria and Tasmania.

- Over the life of the project there were 28 workshops and presentations covering Victoria, South Australia, Tasmania, Queensland, New South Wales and Western Australia.

- There were nine soil health workshops conducted for the viticulture industry held in New South Wales, South Australia, Victoria and Western Australia.

4.1.7 Project Evaluation(s)

There was no formal evaluation of this project.

4.1.8 Project Review

The overall quality of the research in this project was high and the outcomes produced as a result of the project are significant and important to the Australian vegetable industry.

The overall approach of the project was to first evaluate a system for benchmarking or assessing soils used for vegetable production in southern Australia. The tests used were based on the soil-health testing protocol developed by Cornell University. This approach was reasonably successful in specifying particular tests that could be carried out in order to characterise soil. This work was to have been extended over more sites and perhaps with more careful selection of cropping systems given what was learned in phase one. For example, most of the sites selected were used for conventional vegetable cropping, with only a small number of alternative cropping systems included, too few to draw confident conclusions about alternative systems such as organics. There is potential for this benchmarking methodology to distinguish between conventional production (e.g. intensive cultivation, inorganic fertilizer and plastic mulch) and compare that type of cultivation to a high organic matter or minimum-tillage type cultivation.

There were two serious limitations in the design of this project: one was to only include topsoil and the second was to rely heavily on the use of penetrometers for assessment of soil physical health. Any future projects of this type must include and evaluation of subsoil, to at least 30cm, preferably deeper.

The overall thrust of the project was to assess current soil practices, using a wide range of treatments imposed over various sites in Victoria and Tasmania. These treatments ranged from various types of fertiliser, organic amendments, management practices and soil disease-control measures. The project also attempted to evaluate the impact of vegetable production per se on soil health and soil total organic carbon (TOC) levels and this approach has produced some significant results.

The project focused mainly on growers' properties with the exception of some soil disease work in greenhouses, which is beyond the scope of this review. This approach has added significantly to the applicability of the results to industry and across a range of soil types and climates within southern Australia.

The project team made an exceptional effort to communicate the results of its work to industry. There were 28 to 30 workshops or seminars, plus an additional nine workshops for the grape industry, and a significant number of publications, newsletters and presentations at conferences. Despite the strong practical nature of the work, the project team also managed to produce a number of scientific publications and a fourth-year honours project thesis.

The final report can be difficult to understand and in some ways does not do justice to the effort that was put into designing and carrying out experimental work in the field. The report is long (236 pages) and there is an enormous amount of data presented. The main conclusions, however, have been clearly communicated. It is apparent that the project team has, justifiably, placed greater importance on communicating project findings directly to industry via workshops, seminars and industry publications than relying on the final report or scientific papers to communicate the findings.

There may be potential to gain more value from the project team's huge collection of data, particularly the benchmarking studies and the short-term trials. One suggestion is to consider whether there is value yet to be extracted, and whether some form of data mining may be useful in extracting additional value from the data.

In conclusion, the project leader and his team are to be congratulated on an outstanding effort with this project. It has made an important contribution to our knowledge of soil health, particularly in relation to vegetable production in southern Australia. The main outcomes of this project have been clearly stated.

If more work of this type is required, my only proviso is that the project design be reviewed by a recognised soil scientist, and this proviso should apply to any soil benchmarking project.

4.1.9 Recommendations and proposed future work

The recommendations from the project were:

1. That the industry continue investment into soil health research (phase II of the National vegetable soil health program) as this project identified several alternative grower practices, not yet established throughout the industry, which increased profit returns to growers by up to $6,000/ha. Further research is required to ensure consistency across different seasons, climates and a greater range of crops. Present information is mostly targeted at broccoli production on sandy soils, but the practices and soil health indicators developed through this project are likely to translate to other vegetable cropping systems throughout temperate Australia, with minimal future research.

2. That studies continue to monitor the affect of newer sustainable practices on soil-borne diseases, pests and weeds. During this study several important commercially-applied organic amendments increased economically-important diseases, such as club root. It is recommended that the mechanisms of increased disease be determined so that these do not represent a problem when better soil health programs are adopted.

3. That the industry consider investing in a national database as a central repository for the information from soil physical, chemical and biological tests being obtained in benchmarking and field studies. This will enable appropriate thresholds to be developed for different farming systems in different regions and start the development of an advisory system similar to that offered by Cornell University with the soil health “Report Card”. This report card allows growers to make decisions on production practices by using a traffic-light system to relate test results to threshold values for optimum crop yields and soil health.

4. That the industry consider a broad-scale program to continue benchmarking production systems in key production regions in Australia using the best indicator tests established in this project and that of the sub-tropical program conducted by Tony Pattison (VG06100). That a national workshop be held with key researchers across industry to review the findings of this project and the sub-tropical soil health project (VG06100) to further draw out implications for industry and science.

5. That investment continues into the long-term trials established in this project, which are evaluating the effect of repeated applications of organic products to soil to truly identify the long-term benefits from continual use. Key findings may not be available until after 6 to 10 years, as it takes time to build organic carbon and alter soil microbial communities. That growers consider changing crop production systems in southern Australia to those which

reduce tillage, as the benefits that can be achieved by increasing soil carbon are lost at present.

6. That growers consider the following specific changes to their crop production:

7. Replacing calcium nitrate applications at transplanting with ammonium-based fertilizers (e.g. urea-based), preferably with nitrification inhibitors to slow down nitrification and reduce nitrate flow. (Results showed that alternative nitrogen products can increase profit and potentially reduce nitrate flow which is better for soil and environmental health.)

8. Incorporating composted chicken manures rather than applying the manure as a surface mulch (which happens at present) as much of the nitrogen and other nutrient benefit is being lost with the latter application.

9. Using alternative carbon and nutrient-based programs to control pest and diseases (e.g. pH modifiers for control of club root). (However, results also showed that metham sodium can be strategically applied as a soil fumigant, as infrequent use did not disrupt cropping systems and soil characteristics any more than alternative grower practices.)

4.2 Vegetable Plant and Soil Health (VG06100)

4.2.1 Summary

The Vegetable Plant and Soil Health ('VegPASH') project was funded by HAL using the vegetable levy and matched funds from the Australian Government. State Government funding was also provided through the Department of Primary Industries and Fisheries Queensland, the Queensland Department of Natural Resources and Water, the NSW Department of Primary Industries and the West Australian Department of Agriculture and Food.

The Project Leader was Tony Pattison (Queensland Primary Industries & Fisheries, Department of Employment, Economic Development and Innovation), and team members were drawn from all the State Government Departments that contributed funding.

The overall focus of the project was to survey vegetable farms in Australia to determine the main issues related to soil health management and to measure the effects of divergent vegetable production systems on soil properties. Specifically, the research objective was to determine a set of useful indicators for the vegetable industry that could indicate and discriminate between soil management practices and systems under vegetable production.

4.2.2 Scope and objectives

In response to a decline in soil health that has resulted from agricultural activities since European settlement, the project aimed to:

- understand soil health limitations;
- identify improved soil health management practices;
- determine the most appropriate indicators to monitor changes in soil health; and
- determine what information vegetable growers need to implement and progress plant and soil health strategies.

In the Final Report for VG06100 the decline in soil health is said to have revealed itself as soil structural decline, increased surface run-off and erosion, and the need for increased agricultural inputs to sustain plant productivity.

4.2.3 Project team

Project leader: Tony Pattison, Qld DPI.
Project team members: Sue Heisswolf, John Bagshaw, Jennifer Cobon, Stephen Harper, Peter Jones, Lisa Gulino, Carole Wright and Wayne O'Neil (QDAFF); Justine Cox, Nerida Donovan, Fadi Saleh, Andrew Watson, Stephen Wade and Leigh James (NSW DPI); and Bob Paulin (WA Department of Agriculture and Food).

4.2.4 Technical content of the study

There were three parts to the VegPASH project: A snapshot of soil health in the Australian vegetable industry; technology transfer; and recommendations for advancement of soil health in the Australian vegetable industry.

Snapshot of soil health: To determine changes that have occurred in the soil and the sensitivity of indicators to physical, chemical and biological soil properties, 14 paired sites across Queensland, NSW and WA were sampled and a range of soil properties tested. Sites were located in six major vegetable production regions. The paired sites compared a "conventional" vegetable production system with a nearby site where the land manager had implemented a soil management practice that they believed would improve soil health. The soil management practices compared to conventional production were:

- Minimum tillage / mulch systems.
- Organic production.
- Compost application.
- Controlled traffic.

The paired sites used for comparison included a range of soil texture types and vegetable crops and were located over a number of climatic regions.

A total of 31 soil properties were measured at each of the sites:

- Soil physical properties: soil penetration resistance (0-10 cm, 10-20 cm, 20-30 cm); bulk density; aggregate stability; colour; texture.

- Chemical soil properties: nitrate nitrogen; phosphorus (Colwell); phosphorus buffer index (PBI); potassium; calcium; magnesium; exchangeable cations (CEC); exchangeable sodium percentage (ESP); pH; chloride; electrical conductivity (EC); electrical conductivity in a saturated extract (EC_e); organic carbon.

- Biochemical soil properties: organic C; labile C; fluorescein diacetate (FDA); ß-glucosidae; microbial biomass C.

- Biological soil properties: nematodes; bean bioassay rating (to determine the presence of pathogens in the soil).

The project team used the multivariate analysis technique Principle Components Analysis (PCA) to group the results from individual soil tests in an attempt to explain the differences between sites. This approach led to the identification of five groups of soil parameters, which together were able to explain 75% of the data collected. The groupings of soil criteria were characterised as follows:

1. Organic matter
2. Biological decomposition
3. Soil structure
4. Disease suppression
5. Soil surface

The soil test results were then used to try to distinguish between the different soil management patterns across the project test sites. This was done for two reasons: first to test the relative value of the suite of soil health tests used in the study, and second to get some measure of the effectiveness of the soil management strategies.

Technology transfer: The technology transfer activities undertaken by this project were:

- Production of a manual Soil health for vegetable production in Australia.
- Vegenotes Issue 12.
- 4 x PASH newsletters distributed to 2500 growers.
- Soil health information days – 10 field days across NSW, Qld and WA.
- Presentations at the national vegetable conference in Australia.
- Presentation at an ISHS symposium in Sweden.
- One-on-one communications with farmers during sampling.

Recommendations for the Australian vegetable industry: National issues and issues relating to specific soil types were identified and presented in the final report for the project. These are outlined in the recommendations section of this project review.

4.2.5 Key research findings from the snapshot of soil health studies

There were wide ranges in soil properties measured between the different sites in the study with some of the greatest differences found in nitrogen, phosphorus, and cation exchange capacity. There were also wide ranges in soil organic carbon and microbial biomass. The nematodes present were mostly bacteriovore with relatively few plant parasitic nematodes. The bean bioassay showed a generally low level of soil pathogens.

Soil texture was a good indicator of the inherent physical, chemical and biological properties of the soil, including capacity to retain and supply nutrients. Most the sites included in the survey had adequate nutrients, with an oversupply evident at some sites. In vegetable systems surveyed, it appeared that nutrient inputs needed to be better matched to crop needs to improve nutrient use efficiency and reduce nutrient loss off the farm.

Organic matter additions: The sites with additional organic matter tended to have greater organic C and microbial biomass, and lower bulk density (less compacted), but a higher penetration resistance relative to sites without additional organic matter.

Traffic management: The sites where traffic was controlled tended to have greater resistance but lower bulk density, Ca, Mg, CEC and organic C relative to normal traffic management.

Nutrient management: Nutrient content of soils was variable across the sites, but the sites could be classified into three groups. One group of sites had high nitrate nitrogen and two groups of sites had high soil P levels. Farm managers can have a big influence on the soil nutrient status through the application of fertilisers, and in the vegetable systems surveyed it appeared that nutrient inputs needed to be better matched to crop needs to improve nutrient use efficiency and reduce nutrient loss off the farm.

Soil management practices: Soil health indicators were good at predicting and measuring changes in practices, but were poor at determining the differences between farming systems. In general, the more complex the system, the more subtle the changes in management, or the less time between changes in soil management practices, the more difficult it was to detect changes in the soil properties.

There are three possible explanations for this:

- The indicators used were not sensitive to the change or were inappropriate for the farming system.
- Some farming systems had not changed soil properties compared with the conventional systems.
- Too much variability due to soil types or other factors.

The most likely explanation is that the implementation of a particular soil management system did not change soil properties in all cases. Some relevant observations in relation to the different systems were made in the final report, i.e.:

Organic production: Changes in soil properties in organic production systems were influenced by the attitude of the farm manager (had they adopted organic production to develop a better farming system or to take advantage of increased market prices?).

Minimum tillage / mulch systems: Results suggested that soil properties at sites with minimum tillage/mulch systems had changed to the extent they could be uniquely identified from conventional systems. Farms that had adopted these systems had committed to change and invested in new machinery; their attitude to soil health was different to other sites.

Compost application: Several soil health indicators were sensitive to organic matter management practices. The sites that had incorporated compost had applied it as an opportunistic practice and results showed it was difficult to discriminate between the addition of compost from conventional farming practices. In contrast, other methods of organic matter management that had integrated farming practices, such as minimum tillage/mulch systems were able to be discriminated with better accuracy from conventional sites. This suggests that compost addition should not be seen as a quick fix to improve soil health, but rather it needs to be integrated with other farm practices to be able to have a positive benefit on soil properties.

Controlled traffic: The results suggested a strong interaction between physical and biological soil properties and management of traffic movement.

In conclusion, the main findings of the technical aspects of the project were:

1. Soil health indicators were able to detect changes between management practices, but were not as accurate in detecting differences between vegetable production systems.
2. Differences in indicators depended on the type of practice change being adopted and the length of time for which the practice change had been adopted.
3. Soil type, based on soil textural differences was a major factor influencing soil management in vegetable production and the constraints of the different soil types need to be managed.
4. Further work is needed to develop a framework or decision tool that allows vegetable growers to decide the best set of practices to overcome the constraints relating to their soil type. Once this has been decided, the indicators relating to soil functions can be used to determine and monitor changes occurring in physical, chemical and biological soil properties.

4.2.6 Project outputs and outcomes

1. Scientific outputs

Heisswolf, S.; Wright, R.; Moody, P.; et al. (2010) Vegetable production in the dry tropics - nutrient and soil management strategies from Queensland Australia. Acta Horticulturae Issue: 852: 97-106

2. Communication / extension activities

Technology transfer was a strong focus of this project and the following outputs were produced and distributed to vegetable growers in Qld, NSW and WA.

1. The soil health manual Soil health for vegetable production in Australia was developed at the end of the project. It was not extended as part of the VegPASH project, nor did time and resources allow a more rigorous scientific review, particularly in relation to the soil biology sections. Because of this it is titled as a draft and has not been printed, but made available on the Queensland Government Department of Agriculture, Fisheries and Forestry website (http://www.daff.qld.gov.au/documents/PlantIndustries_FruitAndVegetables/Soil-health-vegetable-production.pdf).

2. Vegenote Issue 12: Indicators of soil health is a summary of the manual and is available on the AusVeg database.

3. Four issues of the VegPASH project newsletter were distributed electronically and as hard copies to vegetable growers and industry service providers. A total of 2550 hard copies were sent to 1200 vegetable producers in Queensland, 900 in NSW and 450 in WA. Electronic copies were sent to DPI staff in Queensland and to 200 people nationally in the industry development officer network. Distribution of the final newsletter was hindered by changes in the IDO network.

4. Ten information days were held at the following locations: Menangle (NSW), Bowen, Ayr, North Perth, South Perth, Melbourne, Gympie, Mareeba. Not all the information days planned for NSW were held due to disbanding of grower organisations and were not able to be integrated with other vegetable industry development activities. Information was covered on: what is soil health; soil functions in vegetable production; practices being experimented with by growers to improve soil health; indicators of soil health; soil health issues for the vegetable industry; comments from other growers on soil health; discussion. Total participation was 130 people. Outcomes from the information days:

    - An increase in soil health knowledge - more information on soil carbon and biology sought.
    - Increased interest in indicators of soil health, particularly measuring labile C as an indicator of soil health.
    - Increased interest in minimum tillage/mulch systems (particularly after learning about the case study of its being used successfully in commercial zucchini production in north Queensland).
    - Increased use of compost to amend soil with low organic carbon levels.

5. Presentations at the 2007 and 2009 Australian vegetable industry conferences.

6. Presentation at the IV International ISHS Symposium - Toward Ecologically Sound Fertilisation Strategies for Field Vegetable Production 2008 (Sweden).

3. Geographical coverage within the Australian vegetable industry

The target regions for the project were Queensland, NSW and WA. Collaboration with the Department of Primary Industries, Victoria through VG06090 and VG07008 allowed extension of project findings into other states.

The 14 experimental (soil sampling) sites were located across six major vegetable growing regions within Australia: Bowen/Burdekin; Bundaberg/Gympie; Lockyer Valley; Cowra; Sydney; and Perth. A range of crops was grown on the sampling sites: beans; zucchini; chilli; sweet corn; broccoli; potatoes; leafy vegetables; and cabbages. The soil sampled in the Perth region was sandy; soil sampled in other regions was a mixture of clays and loams.

4. Key soil health attributes included in extension materials

- VegPASH Newsletter 1: Aims of the project, what makes a healthy soil.
- VegPASH Newsletter 2: Results from Gympie farms, results from the Lockyer Valley.
- VegPASH Newsletter 3: Results from North Qld, results from WA, measuring carbon in the soil.
- VegPASH Newsletter 4: Results from NSW, soil health indicators.

The soil health manual essentially explains, with a broad perspective, many of the techniques used in the projects and includes a general background on soils and soil health. It is a high-quality well-written resource publication. In includes a section on how to manage soils to improve soil health. Sections include:

- Part 1: Introduction to soil health
- Part 2: Know your soil and its constraints
- Part 3: Managing common soil constraints
- Part 4: Measuring soil health
- Part 5: Some practices to improve soil health

4.2.7 Project Evaluation(s)

There was no formal review of the project. The soil health manual was sent to a few industry people for review with positive feedback.

The Final Report indicated that vegetable growers have become more interested in soil health management practices as a result of the project. In particular an increase in interest in minimum tillage/mulch systems was reported, and that growers had started experimenting with compost applications on their farms. The research survey allowed a greater two-way exchange of information to develop a better understanding of soil health in vegetable crops.

4.2.8 Project review

The project team has demonstrated a clear understanding that healthy soil is about the physical, chemical and biological properties and how these interact with the crop and the environment. A comprehensive suite of 31 tests was used to quantify the change in soil properties in response to specific soil health improvement measures over six sites in Qld, WA and NSW. These have been explained in detail in the preceding sections of this review. This approach was valid and generated useful data on the effects of these interventions in the medium term. Of particular importance was the assessment of the impacts on soil health of minimum tillage / mulch systems, organic production, compost application and controlled traffic.

Changes in soil properties could not be measured in all cases and this was attributed to either the interventions not being a coherent objective system in the case of organic production, and variability in the extent to which individual growers implemented the systems. Despite these two exceptions, the soil health interventions were effective and excellent data was generated.

There were no measurements or estimates of vegetable crop yields or performance, at least not presented in the final report, and while this would have been difficult to interpret given the range of crops, soil types and management practices, the individual sites were matched, and had this data been collected, it could have made a useful contribution to our understanding of the impact of soil health improvements on the yield and profitability of soil health interventions.

The extension effort associated with this project was extraordinary and a credit to the project team. The VegPASH newsletters summarised the results of work in each region, and this would have been of great interest to growers who always value work that relates as closely as possible to their own farms.

The newsletters were placed on the Soil Knowledge Exchange website (http://www.avike.com.au), but the funding for this was not ongoing and growers might not use the site. Copies of the full newsletters could be included with the final report (summaries are included in the report) on the AUSVEG R&D Knowledge Management website to ensure ongoing accessibility. Vegenote 12 is a summary of the soil health manual and is included on the AusVeg website.

The soil health manual is a well-produced booklet covering a wide range of soil properties and is more of a general soil management guide than specifically focussed on soil health. For example, it covers basic soil properties such as texture, structure, soil horizons and soil type. It does have a section that explains soil health from a vegetable perspective, and it also has a chapter specifically devoted to explaining ways of improving soil health. It meshed nicely with the Ute Guide (subject of the next review) and together these publications provide solid, practical information which growers, agronomists and other professionals servicing the vegetable industry can use to guide and support their soil health-related activities.

The 10 field days were also well run and an excellent initiative from the project team. It will be interesting to see from the results of the soil heath survey (part of this soil health review project) whether these field days made a significant impact among growers.

Presentation of results at the international symposium in Sweden were unlikely to have had any impact on the industry here, however attending the international meeting was likely to have been useful in terms of maintaining international links with other scientists working in this field.

The only scientific output that could be identified was an Acta Horticulture paper from the conference in Sweden, which is not a peer-reviewed publication, although it is picked up by databases. The approach of using PCA to group soil parameters and the success of soil test suites to discriminate between soil health activities and systems was innovative and seemed to be worth the effort of producing a scientific paper in a peer-reviewed journal.

4.2.9 Recommendations and proposed future work

Much of the soil health information available is focused on the environmental impacts of farming, without demonstrating benefits to growers. The approach suggested by Dr Pattison regarding new soil health research from the vegetable industry, is to identify the constraints to production using physical, chemical and biological indicators and relate this to soil functions, which limit crop production. Some constraints are inherent to soil types and others are management-induced.

The soil most important functions are retaining soil structure, nutrient supply, water supply, disease suppression and toxin degradation. The importance of these different functions is dependent on crop, soil type and grower practice.

Management should be targeted at overcoming the most limiting soil constraints and increasing the soil functions related to the soil constraint. For example, in the Bowen area low organic C is constraining long-term production. To increase organic C, minimum-tillage mulch systems appear to be working but there are other production constraints that also need to be addressed, such as soil surface compaction, and water and nutrient management. By addressing the production constraints it is possible to develop systems that start to build soil C and be self-sustaining.

This approach has been used in the banana industry to help suppress plant-parasitic nematodes and Fusarium wilt, using soil health indicators to measure the changes brought about by soil management changes. This is important because implementing changes in management practices, which do not impact on the soil indicators that are constraining production, have little impact in overcoming the constraints themselves and therefore in achieving long-term sustainability.

The project found that there were a number of soil health issues that need to be considered by the vegetable industry for future soil health R&D investment. These were either national issues (issues that affect all vegetable producers regardless of region or soil type) or soil-type related. It was also recommended that a soil health program framework be put in place for the vegetable industry.

National issues:

1. Nutrient management:

    a. Research into critical levels of nutrients for major vegetable crops and different soil types (high levels of N and P show that inefficient use of fertilisers is a common problem; this has associated environmental concerns).
    b. Development and demonstration of tools to help growers manage nutrient inputs on-farm (tools are available that could be modified for the vegetable industry).

2. Carbon management: Soil C management will become increasingly important and it is critical for Australian vegetable growers to have the knowledge and tools that will be required to manage this in the future. The industry should prepare for this.

a. Confusion exists about soil organic matter and soil carbon (C). Terminology, forms of soil C, measurements, how practices impact soil C, and benefits of improving soil C; clear definitions and what they mean for vegetable production are required.
b. Development of a "soil carbon calculator" to assist growers determine how vegetable management practices impact on soil C levels.
c. Information about how soil properties (physical, chemical and biological) and crop production change following a 1% increase in soil C for different soil-textured soil types.

3. Pest and disease suppression - an understanding of how the physical, chemical and biological properties of soil increase or decrease the incidence of soil-borne pests and diseases:

    a. Development of a soil-risk assessment tool for growers to major soil-borne pests and diseases. This would include an understanding of soil limitations, inducing disease as well as soil factors contributing to pest and disease suppression.
    b. Factors that impact on soil borne pests and diseases include:

        - Tillage
        - Cover crops
        - Soil amendments (e.g. lime)
        - Nitrogen management
        - Incorporation of crop residues

4. Soil acidity: There is a fourth area that is likely to be important and was also flagged in project VG07008, and that is **soil acidity**, especially in relation to managing nutrient availability to crops and also in the control of soil-borne diseases such as club root.

Soil-type related issues:

1. Structural stability of clay and loam soil types:
    a. Controlled traffic systems for vegetable production - improvements in soil health, productivity and economics.
    b. Increasing organic matter in clay soil to retain and improve soil aggregate stability and resist erosion.
    c. Managing sodicity and salinity in soil used for vegetable production.

2. Nutrient and water-holding capacity of sandy soil types
    a. Increasing the nutrient and water-holding capacity of sandy soil used in vegetable production in Australia. (e.g. What is the impact of adding organic matter to soil ? Does it cause changes in other soil properties, do diseases problems increase, as has reportedly occurred in root crops?)

Potential new project areas:

VG06100 identified the following potential project areas for soil health research in the Australian vegetable industry:

1. The establishment of a **national soil health program**, run by a single national body to manage soil health research and communication.
2. Development of a soil pest and disease risk-assessment tool for growers.
3. Controlled traffic systems for vegetable production.
4. Increasing organic matter, especially in clay soils, to improve physical soil properties.
5. Managing sodicity and salinity in vegetable soils.

4.3 Healthy Soils for Sustainable Vegetable Farms: Ute Guide & Soil Health Interpretation Courses for Vegetable Growers

4.3.1 Summary

The Healthy Soils for Sustainable Vegetable Farms project was part of the Healthy Soils for Sustainable Farms (HSSF) Program, which was an Australian Government initiative funded through the Department of Agriculture, Fisheries and Forestry (DAFF). The Grains Research and Development Corporation (GRDC) was a major co-funder, and the HSSF Program was managed by Land and Water Australia (LWA). The project ran from March 2006 to August 2008. The HSSF Program provided funding of $350,000; total funding for the project was $662,000 in cash and in-kind contributions.

Helena Whitman (then AUSVEG Environmental Manager) was the Project Leader and the Project Team comprised Dr Alison Anderson (then NSW Vegetable Industry Development Officer, NSW Farmers' Association), Jim Kelly (Arris Pty Ltd) and Dr David McKenzie (McKenzie Soil Management Pty Ltd). The AUSVEG Environmental Committee acted as a project steering committee.

The Healthy Soils for Sustainable Vegetable Farms ('Healthy Soils') project aimed to collate information about healthy soil and its management and make it readily accessible to vegetable growers and their advisors. An industry review (Managing soil health for sustainable vegetable production VG06090) had identified that there was a need for a resource that contained the latest information with respect to soil and land management and this project was supported by HAL and AusVeg. The project also took into account that many vegetable growers have a Language Other Than English background ('LOTE growers') and there is a need for hands-on training to support information provided in the written format.

The primary output of the project was the Healthy Soils for Sustainable Vegetable Farms book, produced in the form of a Ute Guide. Material for the Ute Guide was peer reviewed and then over 9,500 copies of the guide were distributed, including class sets (of 5) to 8 Agricultural Colleges.

Other outputs of the project included:

- Six soil awareness days held over five States, covering a very broad range of soil conditions and crops.
- A one-day course including in-field demonstration of various methods of soil testing.
- A DVD demonstrating the on-farm soil assessments covered in the soil awareness days.
- A training manual linked to Australian National Training Authority: Certificate of Amenity Horticulture RTF03 (Level IV or higher).

Project materials are widely available for continued use in training, and the project has demonstrated a large ongoing demand from growers and advisers for practical information and training in healthy soil management. Project publications are currently being used by eight tertiary training organisations.

4.3.2 Scope and objectives

- Development, publication, promotion and dissemination of a soil identification and interpretation reference for the vegetable industry that can be carried around in a farm vehicle (the 'Ute Guide').
- Development of an instructional DVD based on the Ute Guide for the particular benefit of LOTE growers and growers with poor English reading skills.
- Development of a Soil Interpretation and Management Course in line with the Australian National Training Authority: Certificate of Amenity Horticulture RTF03.
- Identification and appointment of appropriate instructors and/or educational facilities for delivery of the course material to growers and agricultural students. Long-term management of healthy soil information through EnviroVeg.

4.3.3 Project team

Project leader: Helena Whitman (then AusVegG Environmental Manager). Team members: Dr Alison Anderson, Jim Kelly (Arris Pty Ltd), and Dr David McKenzie (McKenzie Soil Management Pty Ltd).

4.3.4 Technical content of the study

The four components of the Healthy Soils for Sustainable Vegetable Farms project are:

- The Ute Guide
- The Soil Awareness Day in-field demonstration workshops
- The DVD
- The Training Manual

The Ute Guide: The Ute Guide covers the soil types in each vegetable-growing region nationally and includes pictorial references that will assist growers to determine if there is a problem in their soil and how to address the problem. It also provides information on interpreting data and soil readings so that growers can more easily understand soil test results and take the appropriate measures.

The guide was produced from relevant Australian and international soil information. The writing style and presentation was in a vegetable-crop production context and the draft was peer-reviewed prior to publication. The design and layout of the Ute Guide was also reviewed by a grower panel to ensure it met the requirements of the target audience.

The Ute Guide was distributed to over 9,000 vegetable growers plus numerous other growers, researchers, advisors, agronomists and members of the public. Seven Agricultural Colleges are using the Ute Guide as part of their Level 3 Curriculum.

The Soil Awareness Day in-field demonstration workshops: The information contained in the Ute Guide was used as a basis for developing the Soil Awareness Day Courses. Six of these days were held at Werribee (Vic), Dareton (NSW), Virginia (SA), Darwin (NT), Stanthorpe (Qld) and Camden (NSW). The South Australian workshop was held in a greenhouse situation where vegetables had been grown continually in the soil. In addition to the training component, the soil awareness days provided an opportunity to assess industry response to the Ute Guide and information about on-farm testing methods to be used in the training resources.

The soil awareness days were attended by more than 150 growers, Landcare personnel, agronomists and some students. Handouts and overhead material developed for the Soil Awareness Days were provided to other facilitators and DPI staff for use during soil workshops conducted in several States.

The Soil Awareness Days were very popular and well received by participants. The number of expressions of interest to run additional days received by the organisers indicate this format is an effective means of delivering information about soil management for the vegetable industry. At the completion of the project in 2008, there were 250 expressions of interest in attending training days that could not be delivered because of funding limitations.

The DVD: This takes growers through the Soil Awareness Day's on-farm testing methods with additional footage of soil pit digging, etc and includes testimonials from growers. The DVD was sent out to the growers who indicated interest in attending Soil Awareness Day workshops where we were unable to meet the demand. The DVD can also be used by Industry Development Officers to target LOTE growers.

The training Manual: A training manual at the level of the Australian National Training Authority (ANTA): Certificate of Amenity Horticulture RTF03 (Level IV or higher) was developed and made available to education and training organisations and also used as additional support material for people attending the soil awareness workshops.

4.3.5 Key research findings

The project was not a research project as such and therefore did not produce research findings. It was more a communications and training project, which collected and communicated existing research-based information on soil management for the vegetable industry.

4.3.6 Project outputs and outcomes

(i) Scientific outputs

Healthy Soils for Sustainable Vegetable Farms: Ute Guide produced and over 9,500 copies distributed to growers and allied industry, including class sets to eight agricultural colleges. The Ute Guide was peer-reviewed by Professor Mike McLaughlin (CSIRO Land and Water, The University of Adelaide) and Dr Cameron Grant (The University of Adelaide) and also a grower panel (the AUSVEG Environmental Committee) to ensure it met the requirements of the target audience (vegetable growers). The Ute Guide was officially launched by the then Minister for Agriculture, Fisheries and Forestry, Peter McGauran at the 2007 Werribee Field Days, attended by more than5,000 visitors. There was also a large number of presentations and industry and scientific meetings, promotional stands and activities at conferences:

- Dr Alison Anderson presented an outline of the Healthy Soils for Sustainable Vegetable Farms: Ute Guide at the Australian Soil Science Society 2006 National Conference.
- 2006 ASSSI National Conference – 250 participants.
- 2006 AUSVEG Annual Conference – 350 participants.
- 2007 HSSF Conference – 350 participants.
- 2007 AUSVEG Annual Conference – 500 participants.
- 2007 Hydroponic & Greenhouse Annual Conference – 250 participants.
- 2007 EMS Keep It Real Conference – 450 participants.

- Presentation to Lachlan grower meeting – 45 participants.

(ii) Communication / extension activities

Six Soil Awareness Days were held in five States and Territories with nearly 200 participants (delivery by other trainers in Vic, Tas and WA). The one-day course consisted of a classroom session based on information provided in the Ute Guide, followed by in-field demonstrations of soil tests and examination of a soil pit/s. Results of tests were discussed. Laboratory tests results were done prior to the workshop for tests that cannot be conducted in-field. Presentation and handout material developed was used by other trainers in Vic, Tas, NT and WA.

Training material and workshop handouts.

Instructional DVD. This serves as a reminder for those who attended workshops and back-up what is shown in still pictures in the Ute Guide. For time-poor growers, it offers practical demonstrations and images and verbal descriptions to assist growers with literacy difficulties. Demonstration of the on-farm soil tests that were covered in the Soil Awareness Days. This is useful for LOTE growers, growers who could not attend a workshop and those with literacy issues. It also assists growers who have attended workshops by boosting confidence in their ability to undertake the tests and then use that information on-farm.

A training manual linked to the ANTA: Certificate of Amenity Horticulture RTF03 (Level IV or higher) was developed and made available to education and training organisations.

Soil Interpretation and Management courses: focused on the soil profile, how to identify and interpret soil structure and chemistry, and how to restore or improve health of the soil.

Articles in industry publications:

- Articles in Vegetables Australia
- Articles in Potatoes Australia
- Industry publications in all States
- Publicity for the Ute Guide and workshops in various industry magazines

Workshops:

- EMS Conference soil workshop – 50 participants
- Beulah Farming Group (Vic) workshop – 31 participants
- Wolseley Farming Group (SA) workshop – 18 participants

(iii) Geographical coverage within the Australian vegetable industry

The Ute Guide was distributed to approximately 9,000 vegetable growers as well as to researchers, advisors, agronomists, members of the public and other farmers on a request basis. Lachlan Catchment Management Authority purchased 200 copies to distribute to farmers (horticulture and broadacre) in its region. Seven Agricultural Colleges requested class sets for use in their Level 3 curriculum.

Soil Awareness Days were held in Werribee (Vic), Dareton (NSW), Virginia (SA), Darwin (NT), Stanthorpe (Qld), Myrtleford (Vic) and Camden (NSW). A Vietnamese interpreter was engaged for the Darwin workshop. As part of other DAFF funding, a workshop was also held in Myalup (WA). More than 150 vegetable growers attended the workshops, as well as agronomists, students,

officers of State Government Department of Primary Industries, Catchment Management Authority and Landcare personnel. Total attendance: 200 people.
The Ute Guide was launched by the then Minister for Agriculture, Fisheries and Forestry, Peter McGauran, at the Werribee Field Days in May 2007. It was also publicised in industry newsletters and magazines and at industry conferences (AUSVEG, TQA).

(iv) Key soil health attributes included in extension materials

The Ute Guide aimed to give vegetable growers answers to their soil questions and, by increasing their knowledge about key soil attributes, give them the confidence to ask the right questions of their agronomists. The Ute Guide covers:

- How to sample soil
- How to measure and describe soil properties
- How to interpret soil tests
- How to improve soil quality
- How to prevent damage to the soil

Text is accompanied by photographs, tables and diagrams to make the Ute Guide easy to read and understand and it points growers to resources to assist them with their soil management decisions.

All the key soil properties that should be considered by land managers are covered: soil structure (form, stability and resilience), pH, nutrients, salinity, exchangeable cations, and soil organic matter. Root growth under ideal soil conditions and the properties of the main soil types used for vegetable production in Australia are also discussed. Growers are encouraged to consider soil management as an integral part of farm business planning.

4.3.7 Project Evaluation(s)

Response to the production and distribution of the Ute Guide was very positive, with feedback coming from a wide range of sectors including the farming, education, extension and science communities.

The HSSF Program report (July 2008) states that this project "has been a well-managed and very effective project that has achieved its objectives and provided valuable new information throughout the vegetable industry, including to members whose usual language is not English. There is further demand for healthy soils training within this industry that could not be met by this project.".

An outcome (not intended) was the interest shown by other industries and education and training organisations in using the project outputs.

Healthy Soils for Sustainable Farms achieved high participation rates, uncovered significant demand for information about soil health, and successfully delivered a range of products, workshops and forums. This was achieved despite difficult drought conditions.

The scale of the projects supported ranges from multi-State projects to catchment-focused initiatives. Some projects took highly sophisticated, multi-factored approaches. Others delivered simple, kick-the-earth guides. All had a valid role in ensuring the ongoing productivity of Australia’s precious soil heritage.

4.3.8 Project review

The project did not include new science, but rather the adoption of R&D and proven soil science and adapted this to the needs of vegetable producers.

The Ute Guide project gave growers information to understand key soil properties and how soil management influences soil health. The Ute Guide is a handy pictorial reference tool, of a size that growers and agronomists can keep in their farm vehicle. It is easy to read and is pitched at giving growers an above-basic level of understanding. The Ute Guide provides growers with everything they need to start measuring and recording the health of their soil, and to put in place management practices that will contribute to farm productivity, sustainability and profitability. It is specifically tailored to the needs of vegetable growers.

The Ute Guide itself is a comprehensive text and covers a wide range of soil health properties such as soil structure, texture, pH, basic soil classification, soil horizons, nutrient holding mechanisms, salinity and so on. It also includes a section on how to dig a soil pit and how to examine the soil on a particular farm. The approach is still somewhat along the lines of tradition soil science, in spite of claims it is a practical hands-on guide. This means there may be a lot of information presented that a grower is unlikely to need in a day-to-day soil management guide. Despite this, there is a great deal of practical, useful information as well as handy guidelines for interpretation of the results of the tests that are described in the book.

The presentation and design is attractive and easy to read. The book itself is sturdy and would indeed survive living in the glove box of a farm ute. This resource gives growers the information they need in an easy-to-understand format, and in a format that is easily taken into the field.

There was a variety of communication methods used by the project team, including a training manual, DVD and the Ute Guide itself. And the soil awareness days were clearly a great success. The use of industry publications to distribute information and promote events was excellent. The DVD gave consideration to people with poor English reading skills.

It was difficult to assess changes in on-farm soil practice as there was no benchmarking survey prior to the project. Project evaluations indicate that growers learnt new information at the workshop. The survey that is part of this current review project will hopefully give some indication of the level of practice change as a result of the Ute Guide and other soil health projects.

Through the development of resources and training workshops the vegetable industry has been provided with the information required to conduct soil tests on-farm and to understand the results of these tests. Growers should also feel confident that they can ask the right questions of their advisors and question information or solutions being offered to them. Growers who attended workshops would have had their skills and confidence enhanced by the hands-on training.

An objective of the project team's was that growers either do some of the soil tests themselves, or get them done by commercial soil-testing laboratories. In terms of soil nutrition testing, this should result in a better match between inputs and crop needs.

4.3.9 Recommendations and proposed future work

There were a number of recommendations made by the authors of the final report for this project, specifically:

1. The development of a generic across-industry Ute Guide that could be made available to all agricultural industry sectors and agricultural students.

2. A simplified translated version of the Ute Guide and other training materials that could be used by agronomists and project officers funded through ACIAR to provide training in developing countries.

3. Catchment management authorities in regional Australia to include soil-training workshops as part of their Action Targets.

The soil awareness days were reportedly highly successful and in demand by growers. A useful initiative could be to fund more of these awareness days and use the resource materials already developed as part of this project.

The Healthy soils for Australian vegetable farms DVD should be uploaded to YouTube and industry members should be advised of this through publications and the AusVeg website. It may be better to break up the DVD into 5-minute segments for YouTube delivery.

5 Soil health survey

5.1 Introduction

The survey was designed to benchmark the uptake of soil health initiatives on-farm in the Australian vegetable industry. It collected valuable information about uptake of soil health initiatives as a result of the HAL vegetable soil health program and benchmarks the current understanding of soil attributes and soil management. The survey was designed to provide a detailed assessment of participant growers' knowledge of the condition of their soil, including physical, chemical and biological soil health. It looked at the following areas:

- Participation in soil projects.
- Ongoing use of project outputs and how they are rated.
- Degree of understanding of subsoil physical/chemical/biological conditions on vegetable farms versus knowledge of the topsoil fertility.
- Knowledge of farm soil type/s.
- Current soil management strategies and any changes as a result of outputs from the HAL projects or the ute guide.
- Identify key physical drivers to adopting soil health measures on farm.
- Identify key economic drivers for adoption of soil health initiatives on-farm.
- Intensity and frequency of soil testing including soil attributes regularly monitored/tested.
- Systems used to display and store soil information on individual farms.
- Perceived value of soil projects.
- Use of soil consultants to test/interpret data.
- Ability to interpret soil tests.
- Whether soil test results are kept to monitor trends over time.
- Use of soil test results as a decision-making tool.
- Gaps in knowledge.
- Presence of soil-borne diseases and their management.
- Preferred information sources and extension methods.
- Drivers/barriers to change.

5.2 Methodology

The survey was designed and constructed using Survey Monkey. A draft survey was reviewed by John Baker (Produce Marketing Australia) and Mike Titley, who provided feedback on design and content. The revised survey was then tested face to face with five growers from North Queensland and also by AHR staff. Following testing, the survey was revised into its final form which is attached to this report as appendix 1. The final survey comprised 28 questions, some in multiple parts.

Sample selection was not a random process. There was a particular emphasis on areas that had been the focus of previous HAL soil health research projects. Specifically, these were: Queensland (North Queensland, Lockyer Valley); Victoria (Cranbourne, East Gippsland and Werribee); Tasmania (Devonport, Launceston, Forth); Western Australia (Perth region and Bunbury); and NSW (Camden, Richmond, central west). Phone interviews were undertaken in other regions where soil workshops were held as part of the HAL soil health program projects, e.g. Dareton/Mildura, Darwin.

The main growers from these areas in most cases were approached personally by Mike Titley and invited to participate in the survey via a face-to-face visit or, if this was inconvenient, via the telephone or Internet. The majority of growers were surveyed face-to-face on the following schedule:

- Queensland (North Queensland, Lockyer Valley) – 5 days
- Victoria (Cranbourne and Werribee) – 3 days
- Tasmania (Devonport/Launceston) – 3 days
- Western Australia (Perth region and Bunbury) – 3 days
- Sydney region (Camden, Richmond, central west) – 4 days

The surveyors from AHR were Mike Titley (N Qld, SE Qld, WA and Vic), Matthew Hall (NSW and Tas), Brad Giggins (SE Qld), Lynn Christie and Gordon Rogers (telephone). Some surveys were completed face to face for AHR by Dale Abbot and Chris Monsour (N Qld), Maurice Schiavon (Bundaberg), Sarah Houston (WA), Rod Hall and Liz Minchin (Werribee), and Liz Hall (Vic).

A total of 130 surveys were completed, which covered 171 separate farms. (This was because some growers had a number of separate farming operations). Of the 130 surveys, 98 were conducted face to face, 21 completed via the web after having made contact with an AHR staff member or partner in the project, and a further 11 growers elected to complete the survey by phone. A total of 210 major vegetable growers across all the main regions were contacted and requested to undertake the survey, but 80 of these farmers did not participate. This meant a success rate for the survey of 62%, which is good by virtually any standards.

Large, well-established commercial vegetable growers in each region were selected and approached to take part in the survey. The approach was to target, through personal approaches, the 20% of growers that grow 80% of the vegetable crops in Australia. The inclusion of a large number of very small growers risked distorting the message being given by the nation's mainstream vegetable growers.

The distribution by State of the 171 farms covered by the survey is shown in Figure 1.

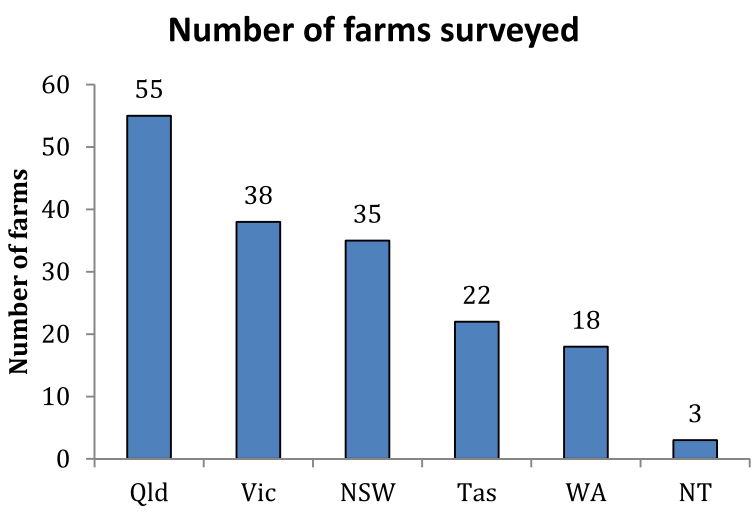

Figure 1. Total number of farms represented by State

The surveys could be undertaken anonymously (the growers were given a choice), but in most cases names were supplied. State, growing region, farm size and primary crops grown were mandatory information so that data can be analysed. Surveys took about 30 minutes to complete.

5.3 Results

5.3.1 Farming operations

The main crops grown by farmers who completed the survey included: brassicas, lettuce, babyleaf spinach and rocket; pumpkin; capsicum; onions; potatoes; sweet corn; carrots; peas and beans; melons; and zucchinis (Figure 2). Most growers judged the health of these crops to be good, with the exception of cucumbers which were only considered to be satisfactory (Table 1). In general, the profitability of growing these crops was also good, excluding carrots, cucumbers, peas and beans, potatoes, and sweet corn, which were considered to be only satisfactory (Table 2).

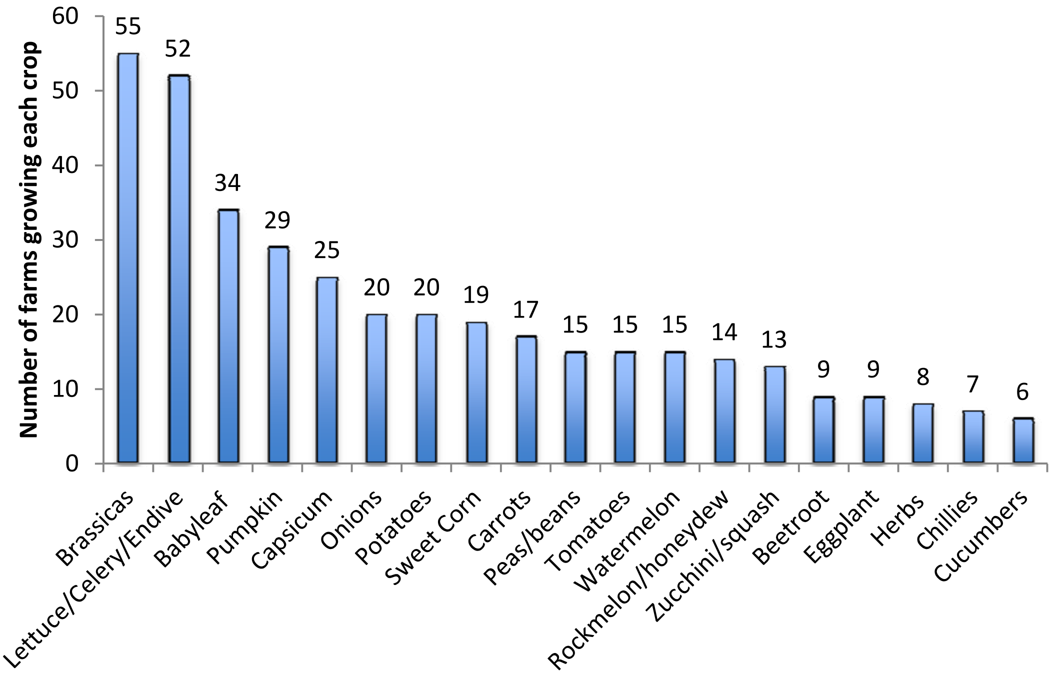

Figure 2. The number of farms growing each vegetable crop. Some farms produce more than one crop type.

Table 1. Health of vegetable crops

Crop	Excellent	Good	Satisfactory	Poor	Very poor
Babyleaf	15.6% (5)	**68.8% (22)**	15.6% (5)	0.0% (0)	0.0% (0)
Beetroot	14.3% (1)	**57.1% (4)**	28.6% (2)	0.0% (0)	0.0% (0)
Brassicas	28.3% (15)	**49.1% (26)**	22.6% (12)	0.0% (0)	0.0% (0)
Capsicum	17.4% (4)	**56.5% (13)**	26.1% (6)	0.0% (0)	0.0% (0)
Carrots	23.1% (3)	**46.2% (6)**	15.4% (2)	15.4% (2)	0.0% (0)
Chillies	25.0% (1)	**50.0% (2)**	25.0% (1)	0.0% (0)	0.0% (0)
Cucumbers	0.0% (0)	33.3% (1)	**66.7% (2)**	0.0% (0)	0.0% (0)
Eggplant	0.0% (0)	**57.1% (4)**	28.6% (2)	14.3% (1)	0.0% (0)
Herbs	0.0% (0)	**80.0% (4)**	20.0% (1)	0.0% (0)	0.0% (0)
Lettuce/Celery/Endive	16.0% (8)	**68.0% (34)**	16.0% (8)	0.0% (0)	0.0% (0)
Rockmelon/honeydew	36.4% (4)	**45.5% (5)**	18.2% (2)	0.0% (0)	0.0% (0)
Onions	23.5% (4)	**52.9% (9)**	23.5% (4)	0.0% (0)	0.0% (0)
Peas/beans	0.0% (0)	**63.6% (7)**	36.4% (4)	0.0% (0)	0.0% (0)
Potatoes	11.8% (2)	**58.8% (10)**	29.4% (5)	0.0% (0)	0.0% (0)
Pumpkin	22.2% (6)	**66.7% (18)**	11.1% (3)	0.0% (0)	0.0% (0)
Sweet Corn	35.3% (6)	**52.9% (9)**	11.8% (2)	0.0% (0)	0.0% (0)
Tomatoes	27.3% (3)	**45.5% (5)**	27.3% (3)	0.0% (0)	0.0% (0)
Watermelon	0.0% (0)	**53.8% (7)**	38.5% (5)	7.7% (1)	0.0% (0)
Zucchini/squash	40.0% (4)	**40.0% (4)**	10.0% (1)	10.0% (1)	0.0% (0)

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

Table 2. Profitability of vegetable crops

Crop	Excellent	Good	Satisfactory	Poor	Very poor
Babyleaf	0.0% (0)	**59.4% (19)**	31.3% (10)	6.3% (2)	3.1% (1)
Beetroot	14.3% (1)	28.6% (2)	57.1% (4)	0.0% (0)	0.0% (0)
Brassicas	3.9% (2)	**43.1% (22)**	41.2% (21)	9.8% (5)	2.0% (1)
Capsicum	28.6% (6)	**38.1% (8)**	23.8% (5)	9.5% (2)	0.0% (0)
Carrots	0.0% (0)	15.4% (2)	**76.9% (10**)	7.7% (1)	0.0% (0)
Chillies	0.0% (0)	**75.0% (3)**	25.0% (1)	0.0% (0)	0.0% (0)
Cucumbers	0.0% (0)	**33.3% (1)**	**33.3% (1)**	0.0% (0)	**33.3% (1)**
Eggplant	0.0% (0)	**85.7% (6)**	14.3% (1)	0.0% (0)	0.0% (0)
Herbs	0.0% (0)	**80.0% (4)**	20.0% (1)	0.0% (0)	0.0% (0)
Lettuce/Celery/Endive	0.0% (0)	**59.6% (28)**	31.9% (15)	8.5% (4)	0.0% (0)
Rockmelon/honeydew	22.2% (2)	**55.6% (5)**	11.1% (1)	11.1% (1)	0.0% (0)
Onions	7.1% (1)	**50.0% (7)**	35.7% (5)	7.1% (1)	0.0% (0)
Peas/beans	0.0% (0)	36.4% (4)	**45.5% (5)**	18.2% (2)	0.0% (0)
Potatoes	6.3% (1)	**43.8% (7)**	**43.8% (7)**	6.3% (1)	0.0% (0)
Pumpkin	16.0% (4)	**44.0% (11)**	28.0% (7)	8.0% (2)	4.0% (1)
Sweet Corn	0.0% (0)	**35.3% (6)**	**35.3% (6)**	23.5% (4)	5.9% (1)
Tomatoes	27.3% (3)	**54.5% (6)**	9.1% (1)	9.1% (1)	0.0% (0)
Watermelon	0.0% (0)	**53.8% (7)**	23.1% (3)	23.1% (3)	0.0% (0)
Zucchini/squash	11.1% (1)	**66.7% (6)**	11.1% (1)	11.1% (1)	0.0% (0)

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

5.3.2 Snapshot of current soil and crop management on Australian vegetable farms

The survey report provides a snapshot of the current soil and crop management of vegetable crops in Australia. The distribution of soil types is shown in Figure 3 with the most common soil types being clay loam (36%) and sandy loam (34%). Soil organic matter levels were low, with 49% of soils rated by growers as having either low (0.5 to 1%) or very low (less than 0.5%) organic matter levels (Figure 4).

There was a heavy dependence on the use of deep ripping (74%) and rotary hoes (70%). This is at odds with other rural industries that have moved further towards reduced tillage and controlled traffic, which can greatly reduce input costs (Figure 5). The type of irrigation most commonly used was sprinkler at 74%, followed by trickle or drip irrigation with a combined usage of 47% (Figure 6). Note, some of the farms surveyed used a combination of sprinkler and trickle irrigation.

Soil-borne diseases were identified as a significant problem. The two most commonly occurring soil diseases were Damping off and Sclerotinia, with 71% of growers saying these diseases occur on their farms. Fusarium wilt was also common at 40%. Next was Nematodes at 32%, then Club root (26%), and Verticillium wilt at 11% (Figure 7).

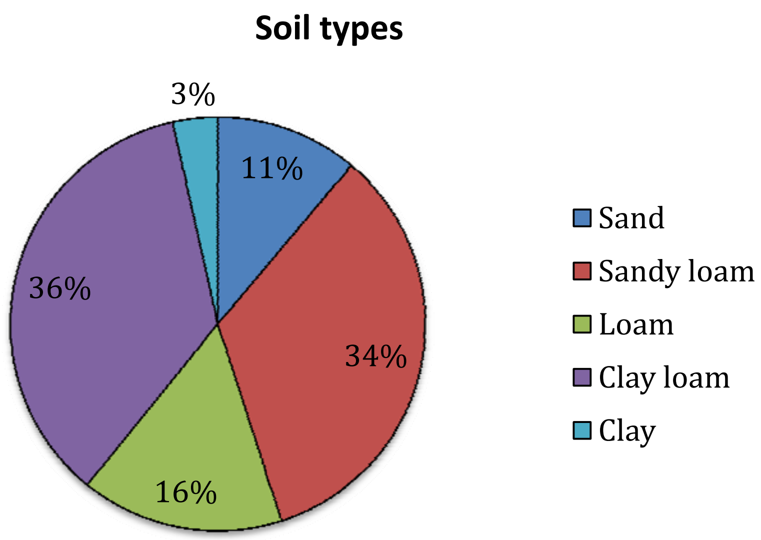

Figure 3. Soil-type distribution in the survey. The numbers in the sectors are % of farms with each soil type.

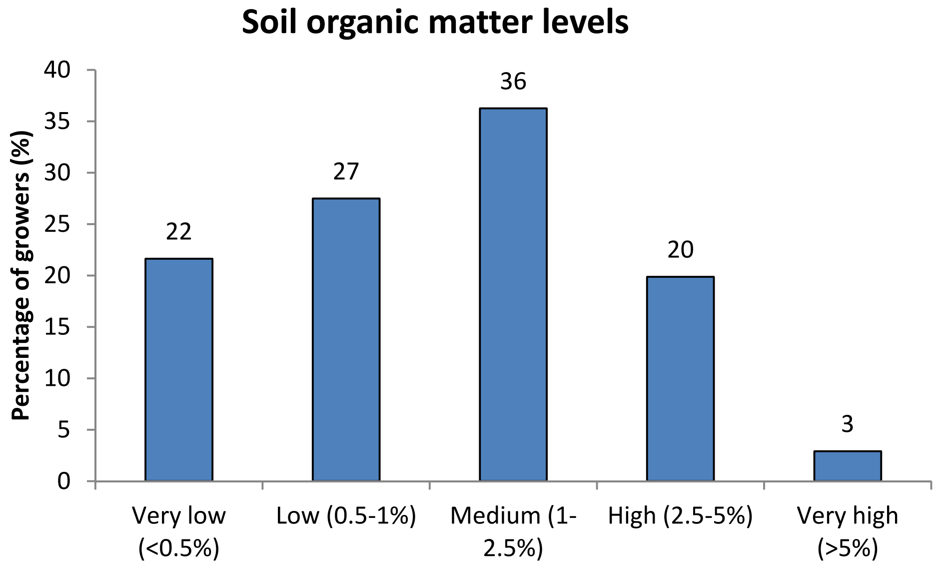

Figure 4. How growers rate the organic matter levels in their soils.

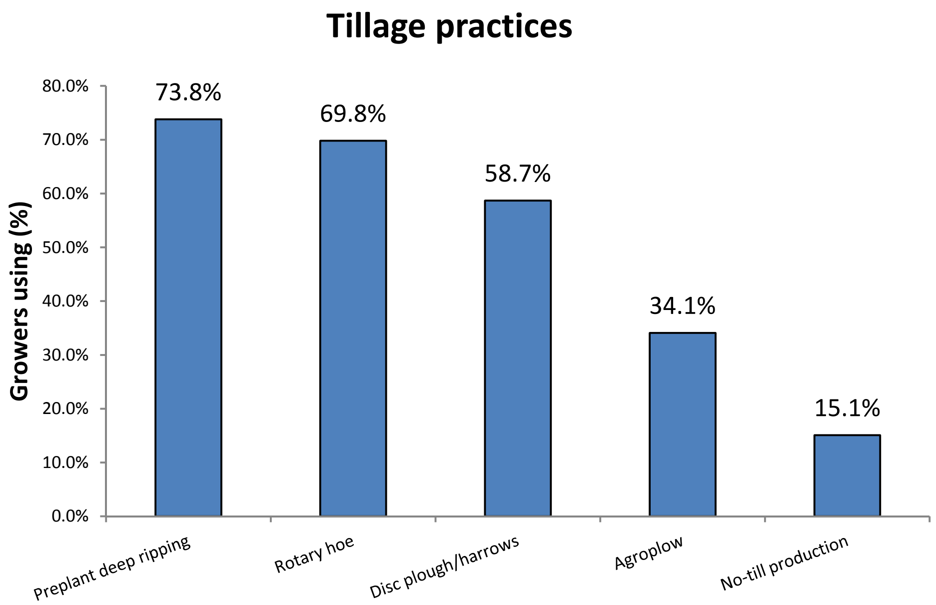

Figure 5. The types of cultivation methods being used on Australian vegetable farms. Note: many farmers use more than one method of cultivation.

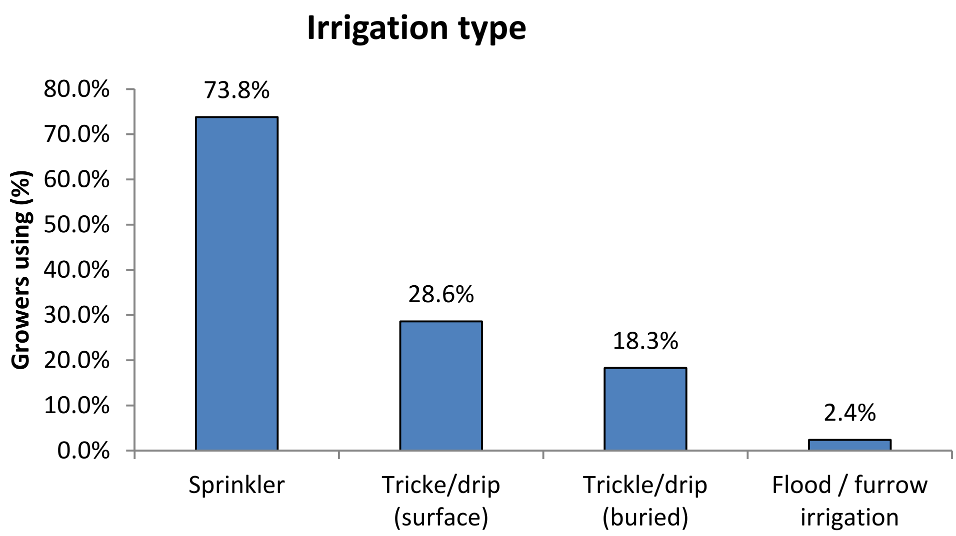

Figure 6. Irrigation methods using on Australian vegetable farms.

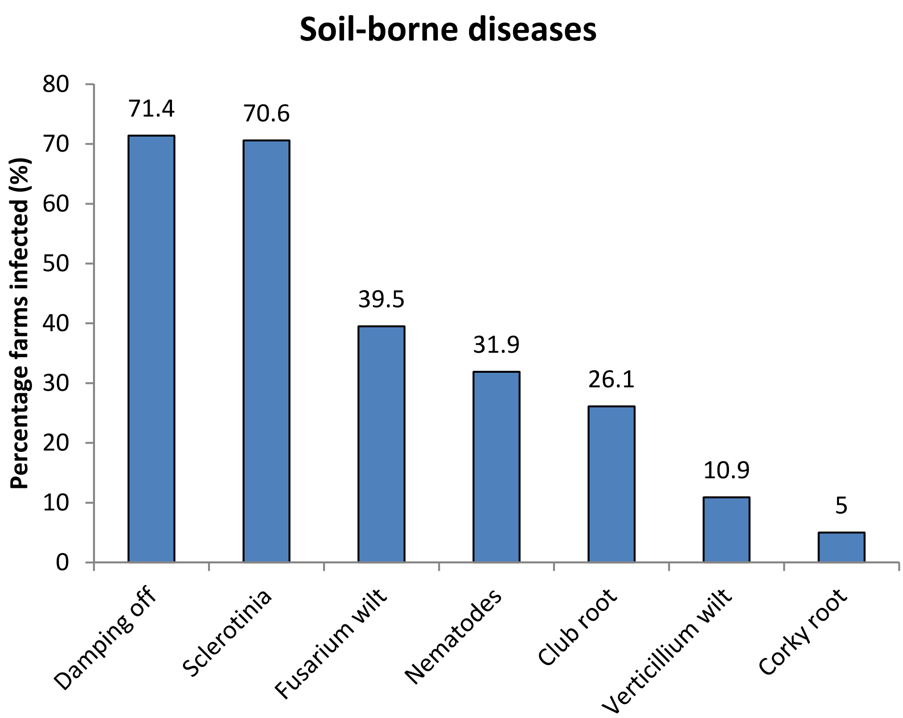

Figure 7. The incidence of soil-borne diseases in Australian vegetable soils.

5.3.3 Soil management

Current depth of knowledge by Australian vegetable growers about the soils on their farms

Growers were given an open question, asking them to describe the physical, chemical and biological properties of their soil, with no other prompting being given. There were 117 responses in total, and each response was examined as to whether it mentioned any of the soil properties listed in Table 3.

Growers generally were aware of soil texture (soil type), structure, pH, nutrients and organic matter levels. There was very little awareness or comment about differences between topsoils and subsoils, soil colour, cation exchange capacity/nutrient holding capacity, soil organisms or disease. Nine per cent of respondents mentioned green manure or cover crops.

Table 3. Responses to question on soil properties

	Soil property	% of growers who mentioned this soil property
Physical		
	Water/drainage	14
	Topsoil/subsoil	5
	Colour	3
	Texture	**30**
	Structure	**21**
Chemical		
	pH	**43**
	Nutrients	**56**
	Salinity/Sodicity	9
	CEC/nutrient holding capacity	5
Biological		
	Organic matter/Carbon	**55**
	Green manure	9
	Diseases	7
	Organisms	11

Growers were then asked about the effectiveness of biological amendments on soil health (Table 4). The amendment rated as effective by the largest number of growers (71%) was green manure crops. Other soil amendments rated as effective by a significant number of growers were composted manure (44%), biological stimulators (29%), EM (27%) and seaweed extracts (33%). Composted green waste, raw manures composted on site and unincorporated cover crops had not been used by almost 70% of growers.

Table 4. Effectiveness of soil organic amendments

Soil Amendment	Effective	Ineffective	Don't know	Have not used
Composted green waste	17.4% (19)	5.5% (6)	8.3% (9)	**68.8% (75)**
Composted manures	44.3% (51)	2.6% (3)	5.2% (6)	**47.8% (55)**
Raw manures composted on site	24.3% (26)	0.0% (0)	2.8% (3)	**72.9% (78)**
Green manure crops - incorporated	**71.4% (85)**	0.8% (1)	9.2% (11)	18.5% (22)
Cover crops - unincorporated	23.9% (26)	1.8% (2)	7.3% (8)	**67.0% (73)**
Biological stimulators	29.1% (32)	6.4% (7)	23.6% (26)	**41.8% (46)**
EM (Effective Microorganisms)	26.6% (29)	4.6% (5)	18.3% (20)	**50.5% (55)**
Seaweed extracts	32.5% (37)	7.9% (9)	19.3% (22)	**40.4% (46)**
Other	22.2% (6)	3.7% (1)	0.0% (0)	**74.1% (20)**

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

5.3.4 Barriers to change

Growers were asked whether they had ever changed any soil practices to achieve outcomes such as higher yields, less disease, improved sustainability or better financial returns. The response to that question was 'yes' for almost all of the farmers who participated in the survey. In fact, improvements in soil management were judged successful by at least 90% of the growers (Table 5). This is a highly encouraging result and demonstrates that Australian vegetable growers place a high degree of importance on the correct management of soils in the conduct their vegetable farming operations.

Growers were then asked, when they chose not to improve a soil management practice, why? (Figure 8). The most common reasons given by growers were cost (67%), followed by lack of information (45%), then uncertainty about impacts on crop yield (36%), economic returns (35%) or direct impacts on the soil (30%).

Table 5. Have you ever changed your soil health practices to achieve any of these outcomes? If so, how successful were these changes?

Objective of soil management change	Yes	Successful	No difference	Worse than before
Higher crop yields	100.0% (108)	**89.8% (97)**	3.7% (4)	0.0% (0)
Less disease	98.0% (96)	**89.8% (88)**	5.1% (5)	0.0% (0)
Long-term farm sustainability	99.0% (100)	**90.1% (91)**	3.0% (3)	0.0% (0)
Less soil erosion	96.6% (57)	**94.9% (56)**	0.0% (0)	1.7% (1)
Less water runoff	97.3% (73)	**92.0% (69)**	2.7% (2)	0.0% (0)
Higher short-term financial returns	98.6% (71)	**90.3% (65)**	5.6% (4)	1.4% (1)
Higher long-term financial returns	98.8% (84)	**92.9% (79)**	3.5% (3)	0.0% (0)

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

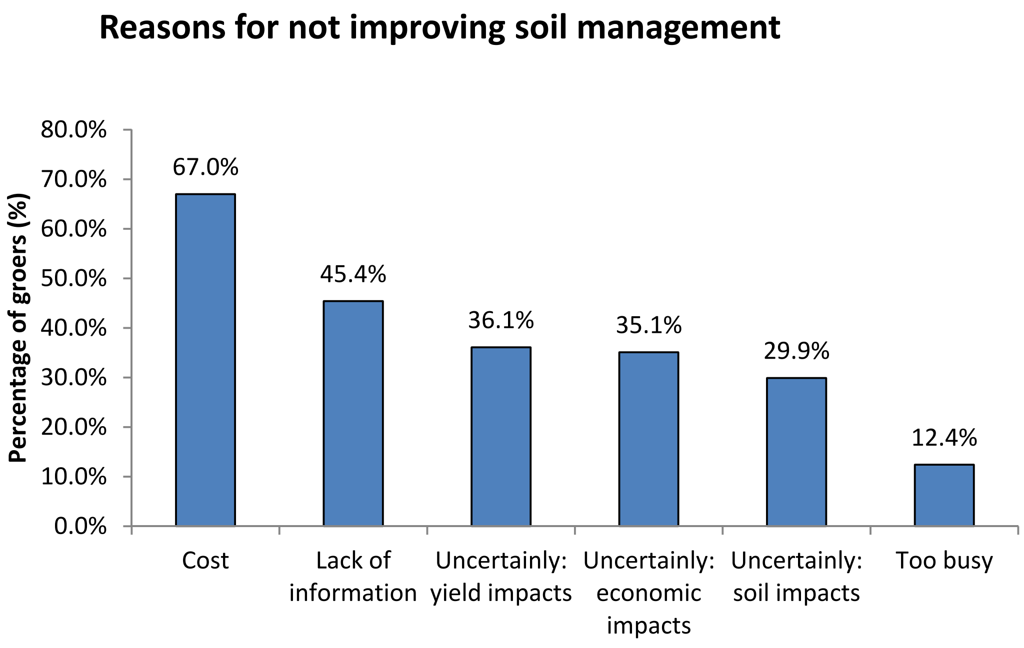

Figure 8. When growers choose not to make a particular improvement in their soil management, what is the most common reason?

5.3.5 Soil Testing

Soil testing was used by 98% of the vegetable growers questioned in the survey (Figure 9). Growers were asked how often they test soils. The most common response was 'every year' for 57% of growers, and 'every crop' for a further 23% (Figure 10). This means 80% of growers are testing their soil at least annually, which is an exceptionally high rate of soil testing and a very encouraging finding.

Seventy per cent of growers test topsoil only, which means just 30% of growers are testing their subsoil (Figure 11). Most topsoil testing is in the 0 to 15 cm range of soil depth, but the roots of most vegetable crops extend well below this depth. There is an opportunity to encourage more growers to take up testing and managing their subsoil, which should result in better crop performance.

Table 6 shows how growers interpret their soil test reports. The two most valued sources of information are from consultants (47%) and growers doing their own interpretations (46%). Thirty-six per cent of growers thought the information on the soil test report was important, but a similar proportion thought that information coming from fertiliser suppliers or resellers was only useful as a guide. Interestingly, 82% of growers thought that farm management software was of no use at all in assisting to interpret the soil test reports.

The information from soil tests is used to good advantage by growers with 76% always using previous test reports to monitor changes in soil properties over time (Figure 12). However, 93% of growers use paper records, and only 43% enter data into databases or spreadsheets. There is some reliance on records maintained by consultants (23%) and about 20% of growers are storing soil test information in the form of maps (Figure 13).

There is a significant amount of soil testing used for identifying soil pathogens and 53% of growers report having sent a soil sample for pathogen (disease or nematode) testing (Figure 14).

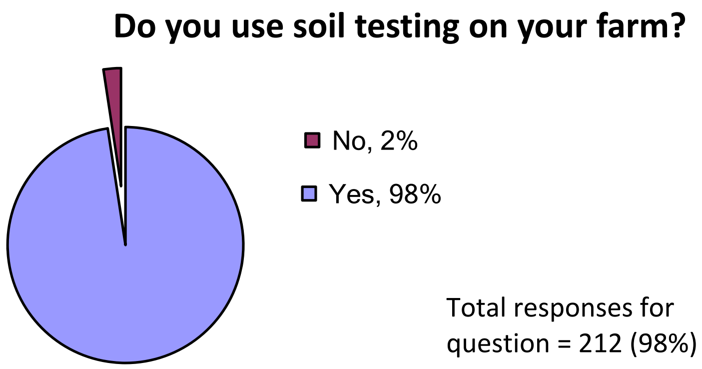

Figure 9. Percentage of growers using soil testing.

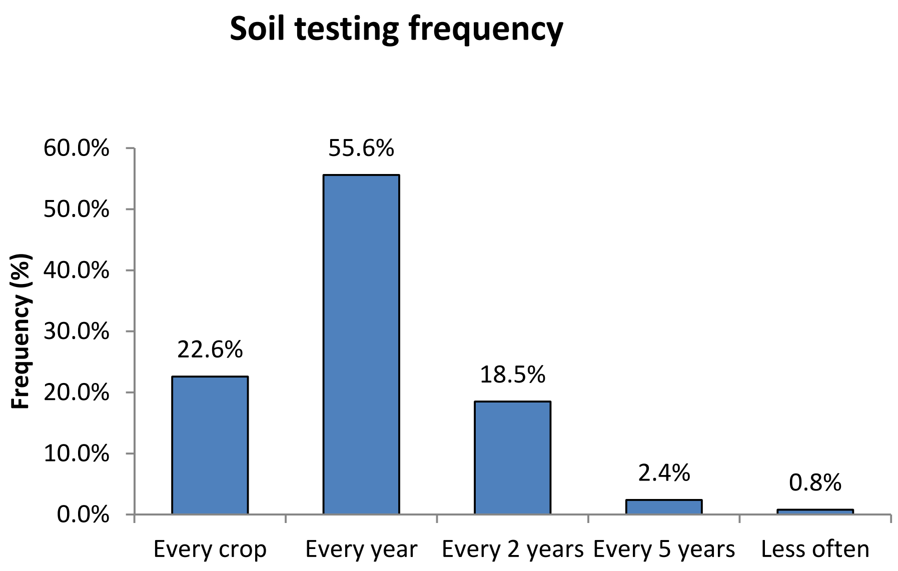

Figure 10. How often Australian vegetable growers test their soil.

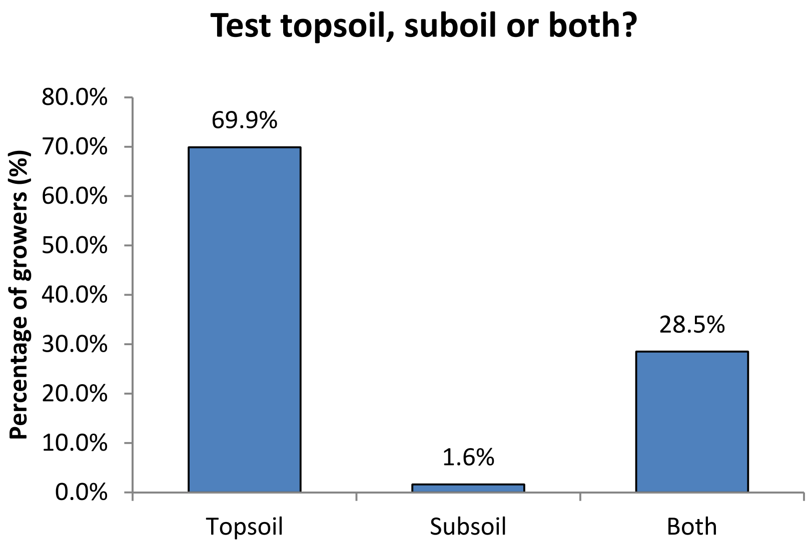

Figure 11. When Australian vegetable growers test their soil, do they test topsoil, subsoil or both?

Table 6. How the various interpretations of soil test results are rated by growers.

Source of information	Essential	Important information	Useful as a guide	No use at all
Consultant's advice	**46.6% (55)**	30.5% (36)	17.8% (21)	7.6% (9)
Fertiliser supplier or reseller advice	15.0% (16)	22.4% (24)	**36.4% (39)**	26.2% (28)
Recommendations on the soil test report	23.7% (28)	**36.4% (43**)	33.9% (40)	5.9% (7)
Your own interpretation of the results	**45.8% (54**)	30.5% (36)	14.4% (17)	9.3% (11)
Farm management software	6.5% (5)	3.9% (3)	7.8% (6)	**81.8% (63)**

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

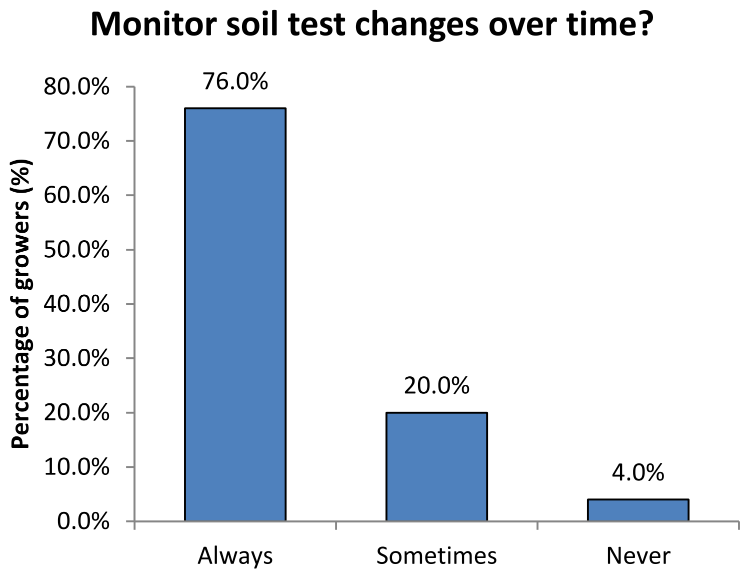

Figure 12. How many growers refer to previous soil test reports to monitor changes to their soil over time.

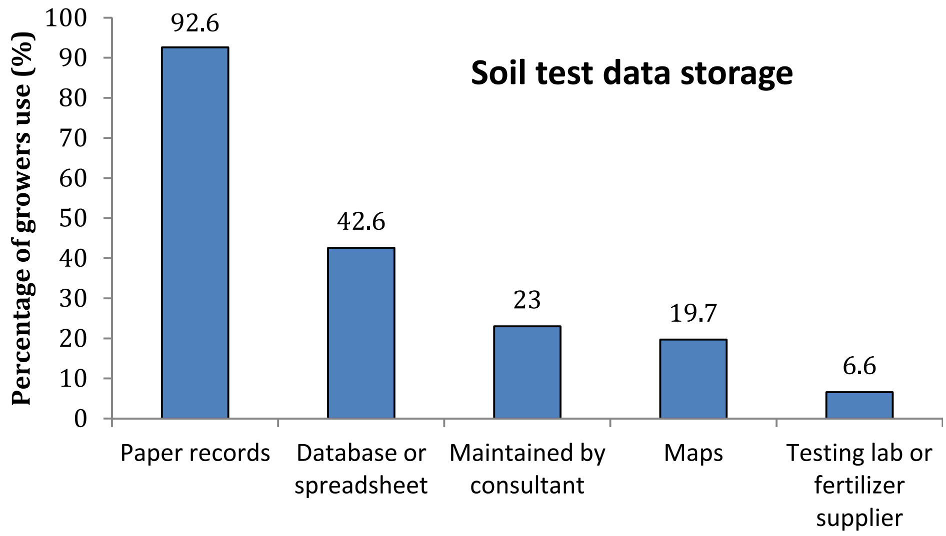

Figure 13. Data storage methods being used on vegetable farms in Australia.

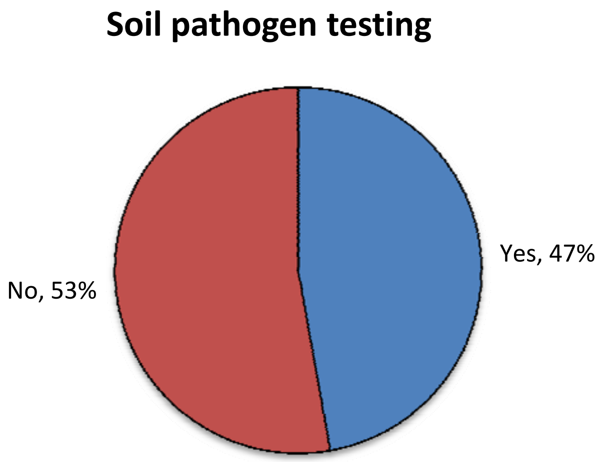

Figure 14. How many growers have ever sent a soil sample for pathogen (disease or nematode) testing.

5.3.6 Uptake from the HAL soil health program

Vegetable growers were first asked if they had been involved in **any** soil health related activity in the last 5 years. The results shown in Figure 15 indicate very high levels of involvement in activities including field days, workshops or seminars, having had a research trial conducted on their farm, or having been to an industry conference in Australia. The same growers were then asked if they had direct involvement in a HAL-endorsed soil health project, and only 28% and answered yes. This suggests a higher level of involvement in broader soil-related activities outside the confines of the HAL soil health program (Figure 16).

The main reasons given for this discrepancy were:

- **Many growers undertake private (non HAL) research.**
- **Involvement in projects outside the HAL soil health program**. Projects and activities recalled included: nitrate monitoring project, compost trials, controlled traffic research, biofumigation work (ServeAg), Bayer soil health group, GLP pesticide residue trials, Sclerotinia trials, Werribee field days, HAL soil mapping project, and green waste project.
- **Attendance at more general conferences/field days**: the Werribee Field Days and the AusVeg national conferences were mentioned.

Specific researchers mentioned in relation to soil health included: Ian Porter, Sue Heisswolf, Liz Minchinin and Steve Harper, and specific research providers mentioned included: QDAFF, Vic DPI, Muirs, ServeAg/Peracto, and AHR.

Growers were then asked about the usefulness of various specific resource materials in relation to providing information on soil management (Table 7). The highest-ranking outputs were AusVeg VegeNotes, Vegetables Australia magazine, Good Fruit and Vegetables magazine, factsheets and newsletters. In relation to the Soil Heath Ute Guide, 37% of growers found this useful or very useful. However, 33% of growers claimed they had never heard of it, which is of some concern given that this publication was sent to all vegetable growers in Australia. In addition, 28% of growers claimed they had never heard of any output from any soil health project, although 43% of growers said they found specific outputs of any soil health projects either useful or very useful.

Other resources specifically mentioned by growers as useful included:

- WA grower magazine (mentioned 10 times).
- Resellers.
- Consultants.
- DAFWA development officers.
- Other magazines.
- Factsheets specific to the crop being grown.
- Fertiliser company soil information manual.
- Cornell University website.
- Internet.
- Support from Snack Brands (potatoes).

Growers were then asked if they had changed their soil management practices as a result of any of these projects or outputs and 61% of growers responded ‘yes’. (Figure 17).

When asked about the communication methods growers preferred for communicating research outputs in relation to soil health, the most useful methods in order of importance were:

1. Talking to other growers.
2. Consultants
3. Field days or field walks
4. Information via websites
5. Training/workshops
6. Printed factsheets
7. Research project reports
8. Video/YouTube presentations
9. Audio presentations

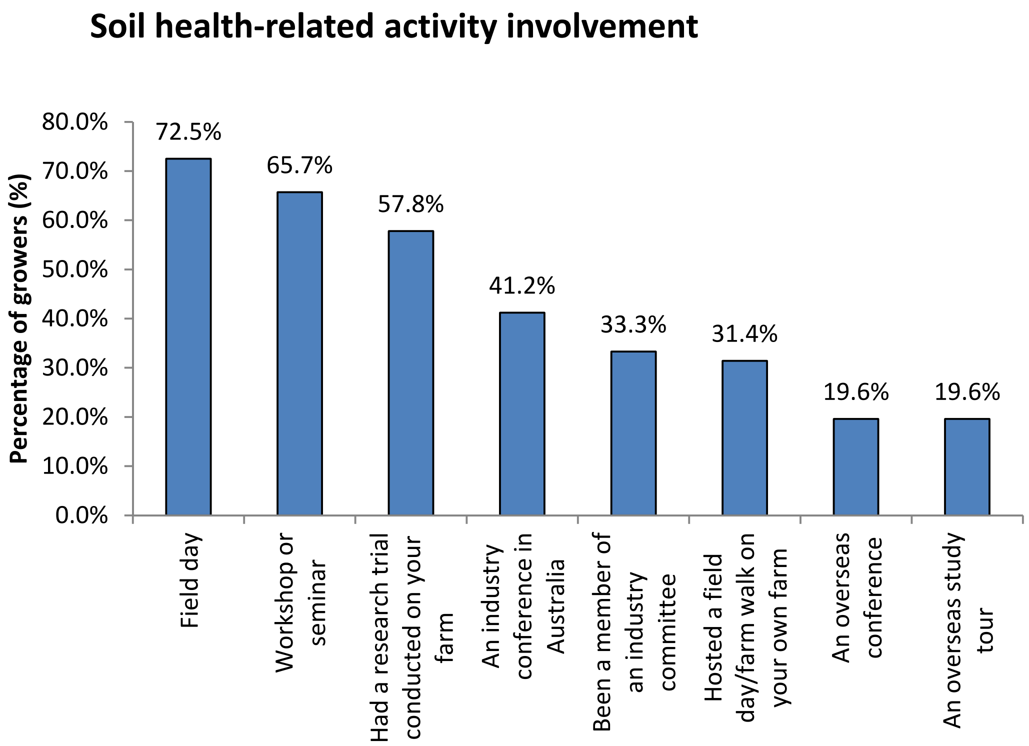

Figure 15. The proportion of Australian vegetable growers who have been directly involved in a soil health-related activity in the last 5 years.

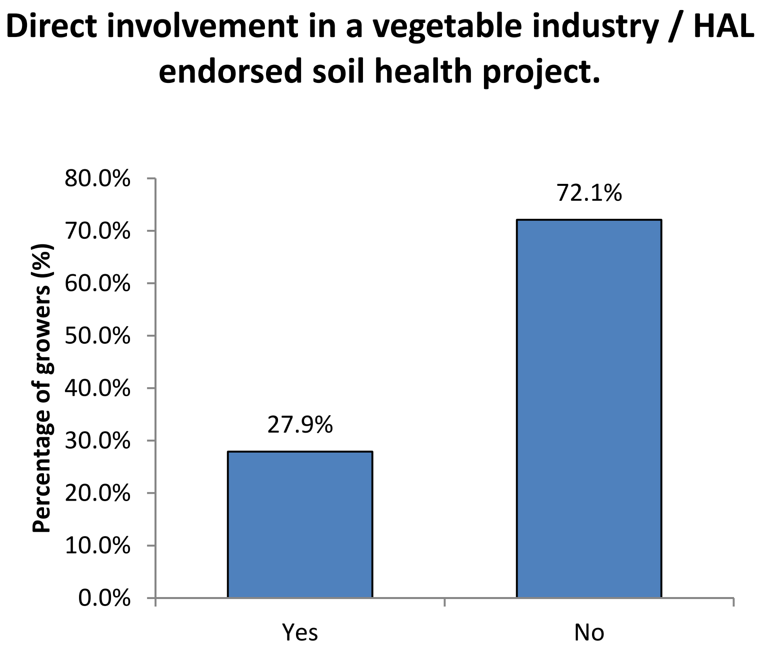

Figure 16. The proportion of Australian vegetable growers who have been directly involved in a HAL or vegetable industry soil health project in the last 5 years. 122 (94%) of growers answered this question.

Table 7. The effectiveness of various resources and information sources in providing information on soil management.

Resource material	Not aware of it	Never used	Marginally useful	Useful	Very useful	Rating Average
Good Fruit and Vegetables magazine	5.1% (6)	17.8% (21)	28.8% (34)	**38.1% (45)**	10.2% (12)	3.31
Factsheets	8.7% (10)	16.5% (19)	19.1% (22)	**50.4% (58)**	5.2% (6)	3.27
AusVeg VegeNotes	5.4% (6)	12.5% (14)	35.7% (40)	**43.8% (49)**	2.7% (3)	3.26
Vegetables Australia magazine	8.8% (10)	16.7% (19)	27.2% (31)	**41.2% (47)**	6.1% (7)	3.19
Newsletters	8.9% (10)	12.5% (14)	31.3% (35)	**46.4% (52)**	0.9% (1)	3.18
Advertisements	9.3% (10)	28.7% (31)	37.0% (40)	**23.1% (25)**	1.9% (2)	2.80
Outputs of any soil health project	28.1% (32)	12.3% (14)	16.7% (19)	**38.6% (44)**	4.4% (5)	2.79
Soil Health Ute Guide	**33.3% (38)**	18.4% (21)	11.4% (13)	29.8% (34)	7.0% (8)	2.59
Other	4.5% (1)	9.1% (2)	13.6% (3)	**40.9% (9)**	31.8% (7)	3.86

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

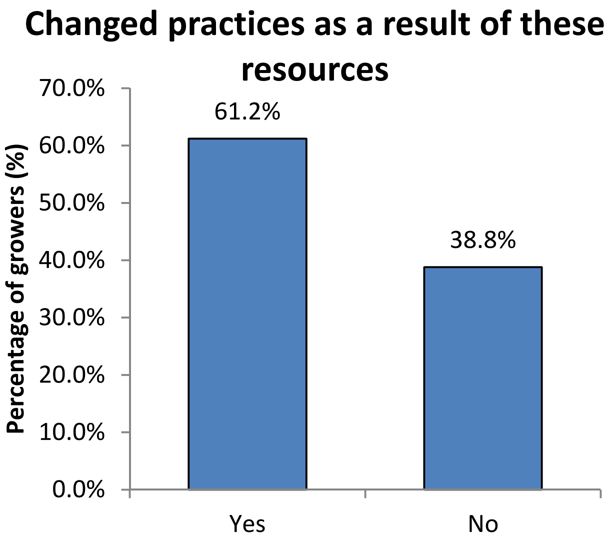

Figure 17. The proportion of Australian vegetable growers who have changed the soil management practices as a result of HAL / AusVeg soil health project outputs

Table 8. The usefulness of different communications methods for communicating information about soil health.

Communications method	Not useful at all	Marginally useful	Useful	Very useful	Rating Average
Talking to other growers	4.2% (5)	9.3% (11)	27.1% (32)	**59.3% (70)**	3.42
Consultants	6.8% (8)	13.6% (16)	**40.7% (48)**	39.0% (46)	3.12
Field days or field walks	6.0% (7)	12.0% (14)	**47.0% (55)**	35.0% (41)	3.11
Information via websites	11.6% (13)	5.4% (6)	**48.2% (54)**	34.8% (39)	3.06
Training/workshops	6.8% (8)	18.8% (22)	**54.7% (64)**	19.7% (23)	2.87
Printed factsheets	5.3% (6)	28.3% (32)	**57.5% (65)**	8.8% (10)	2.70
Research project reports	12.5% (14)	31.3% (35)	**41.1% (46)**	15.2% (17)	2.59
Video/YouTube presentations	22.1% (25)	20.4% (23)	**43.4% (49)**	14.2% (16)	2.50
Audio	**55.8% (58)**	17.3% (18)	23.1% (24)	3.8% (4)	1.75

Note: The numbers in brackets are the actual numbers of responses. The numbers in bold show the highest scores in each category.

5.3.7 Areas in which growers would like more training

Growers were asked in what aspects of soil health they would like to improve their knowledge. There were 96 responses to this question and those responses are summarised in Table 9. The main areas requested for training were:

1. **Soil biology and microorganisms**: The overwhelming response was in relation to soil biology and microorganisms, with more than one-third of all respondents indicating this is an area in which they would like to improve their knowledge.
2. **Soil-borne disease control (11%).**
3. **Interpretation of soil test results (10%).**
4. **Biofumigation / alternatives to metham sodium (7%).**
5. **Fertilizers and nutrition (7%).**

Table 9 Areas of personal knowledge improvement

Improve personal knowledge in	Number of responses
Soil biology / microorganisms	36
Soil-borne disease control	11
Interpretation of soil test results	10
Biofumigation / alternatives to metham sodium	7
Fertilizers and nutrition	7
Soil pH	4
Organic amendments	3
Soil physical properties	3
Grower networks and advice	2
Soil carbon	2
Soil chemistry	2
Long-term-care of soils	1
Alternative to NPK	1
No-till	1
Water	1
Cultivation	1
Mulching	1
Conflicting information	1

5.3.8 Priority areas for future research

Australian vegetable growers were asked where they thought the soil health research efforts should be directed in the future. There were 97 responses in this section (see full list in Table 10), and the most popular responses were:

1. **Soil health research should continue**: virtually all respondents thought soil health research should continue.
2. **Soil-borne diseases**: 51% of respondents nominated this as an important area of soil research for the Australian vegetable industry. The soil-borne diseases identified as requiring attention, in order of importance, were:
    - Sclerotinia
    - Pythium
    - Anthracnose
    - Rhizoctonia
    - Verticillium
    - Fusarium (melons)
    - Club root (brassicas)
    - Nematodes
3. **Biofumigation** was nominated by 15% of respondents.
4. **Nutrition** – general, nitrogen nutrition and N-fixation.
5. **Soil biology** – general.
6. **Controlled traffic and no-till.**
7. **Soil health** – general.
8. **Organic composts.**

Table 10. Industry-wide issues worthy of research and/or extension efforts

Industry-wide issues to address (research and/or extension)	Number of responses
Soil-borne diseases – controls	49
Biofumigation	14
Nutrition – general, nitrogen nutrition and N-fixation.	9
Soil biology – general	7
Controlled traffic and no-till	7
Soil health – general	6
Organic composts	5
Better communication of existing research	4
Mulching including biodegradables	3
Cover crops	2
Soil carbon	2
Biological farming / organics	2
Localized research	2
Microbial diversity	1
Biological control of soil disease	1
Biological activators	1
Wetting agents	1
Across industry approach to soil health research	1
Precision farming	1
Irrigation	1
Crop rotations	1
Soil pH	1
Training	1

5.3.9 General comments about soil health research in Australia

Growers were asked a final, open question about soil health research in Australia. The question was answered by 60% of growers, and their categorised responses are presented in Table 11. Three major messages emerged:

1. **Soil health research should continue**. The overwhelming sentiment from growers was that research and communication activities in the area of soil health, or soil management, should continue. There were many comments about the importance of soil research, particularly in relation to soil-borne diseases, productivity, sustainability and improving general understanding of soil biology in relation to vegetable crop production. The current definition of soil health could be broadened; it is research into soils that is valued, not just in the specific area of soil health.

2. **Strong regional focus**. Research projects should have a strong regional or local focus. The regional differences relating to climate, soil type and the crops produced mean that generalised research with a national focus is of limited value to vegetable growers. Much more effective would be research projects aimed at correcting specific issues that affect vegetable growers in their own region.

3. **Effective communication of research results back to growers**. This related to communicating the results of research projects back to growers and also communicating existing soil health information to growers in a usable form. The information should not be trivialised or oversimplified, but should be presented in a way that is clear and requires the minimal investment of time by the grower to incorporate this information into actions that can be readily implemented on their own farm.

Table 11. General comment on soil health research

General comments for soil health research in Australia	**Number of responses**
Maintain research in the area of health (especially in relation to disease, productivity and sustainability)	21
Effective communication back to growers	11
Strong regional or local focus	10
Agronomists and consultants are important	7
Do not approve of the projects on which levy funds are spent	5
Increase profitability	5
Long-term sustainability	4
Green manure crops / cover cropping	3
Use private research	3
Fertiliser use efficiency	2
More funding for the Lockyer Valley	2
More research in East Gippsland	2
Biofumigation	1
Content more important than method of communication	1
Disagree with current research priorities	1
Education	1
Involve universities more	1
Liquid fertilisers	1
More cross-industry research into soils	1
More field days	1

More no-till research	1
More realistic commercial-oriented research	1
More research into manures	1
More research on compost and organics	1
More soil management demonstration sites	1
More use of soil research experts	1
Pressure on productivity forces overuse of land	1
Soil research into new production systems	1

5.4 Feedback from face-to-face surveyors

5.4.1 Level of nutritional uptake

Overall, growers' understanding of soil nutrition is good.

- The majority of growers had made amendments to their soils with good results.
- All growers soil test and use consultants /resellers and themselves for interpretation.
- Many growers are looking for sustainable organic inputs.
- Ex Victorian DPI researcher Craig Murdoch's research model for the tip burn project was highly regarded.

5.4.2 Management of organic matter – green manure and bio-fumigants

- Generally there is medium/high use of either composted green waste/manures or incorporated green manure.
- Nth Queensland, Eastern Darling Downs, East Gippsland, Manjimup and some Mornington Peninsula growers use sorghum, rye grass, barley etc and composted manure.
- Gatton growers bare-fallow in the summer.
- Mornington Peninsula growers incorporate crop residue.
- Werribee and WA sand growers (north and south of Perth) tend not to use biofumigant or green manure cover crops.
- NSW growers are just starting to look into bio-fumigants and green manure crops.

5.4.3 Soil-borne diseases

- Growers generally know what diseases their soils have and how to handle them, however there are some areas that need work.
- Damping off needs work, especially for the babyleaf and lettuce industry. (This suggests the need for a working group.)
- Fusarium wilt. Most growers are aware of the need to use appropriate varieties.
- Verticillium wilt. Increasing problems are being experienced in leeks on sand and cauliflowers in the Werribee area.
- Club Root has been overworked in terms of research but there may be a communication issue that can be revisited.
- Sclerotinia. Many growers are still using chemicals and are not aware of the research by Knoxfield DPI. (Suggests a communication problem.)
- Nematodes. There is reliance on metham sodium rather than bio-fumigants.
- Anthracnose needs more work. Victoria especially has had severe problems in wet seasons since 2009.
- An issue for growers is the need to understand the triggers that are involved in outbreaks of soil-borne diseases.

5.4.4 What gaps are there in research? What needs to be done in the future and what resources are required?

- Some growers mentioned a disconnection between the issues growers' want to be addressed and the projects which are approved by the IAC.
- Generally speaking, it seemed that growers were comfortable with physical and chemical knowledge of their soils.
- There is a gap in understanding the biology of their soils, particularly concerning the addition of green waste, composted manures and green manure crops, and the residual effect in the soil. Growers would like to know the amount of Isothiocyanates in biofumigants and to be able to relate that to a litre/hectare application.
- Research that leads to a soil biology scale (similar to pH scale) for organic content was cited as something that growers would value.

5.4.5 Desired methods of communication

- Field days and field trips were considered the most beneficial.
- Web/YouTube communication was also highly rated.
- "Not another wordy publication, please!" was a commonly expressed sentiment.
- More importantly, if the output of research is a major report, it also needs to be condensed to present the most important information, and in layman's language.
- Regions want local-based research relevant to their crops (especially in Lockyer Valley & East Gippsland).
- High-end growers want direct access to the researcher. The sugar industry was quoted a number of times as having the model right, which links researchers directly to the grower.
- Not enough literature research is done, which results in research levy monies being spent on research that has already been conducted overseas.

5.4.6 Other general observations by face-to-face surveyors

- Poor understanding among growers of how HAL works and how the levy works.
- Growers' management of organic matter– green manure and bio-fumigants – was good. Most had a solid understanding of the need for increasing the amount of OM in their cropping systems.
- Most growers used cover crops that were incorporated. Only a few mentioned bio-fumigants, but anyone who had soil-borne diseases was aware such things as mustard and "fumigator-sorghum".
- Most growers understood the importance of rotating between crops and using registered fungicides. Two growers mentioned the use of soil fumigants with their level of knowledge being limited to "how to manage the disease". Only one grower had an in-depth understanding of disease cycles.
- In general, all growers thought more soil research is required across all areas.
- A clear message was that research must be targeted to industry problems – not just "some researchers doing work in an area that they have interest in!".
- Some areas for research favoured by growers included:
    - Soil-borne disease, specifically Sclerotinia in lettuce and carrots.
    - Soil biology.
    - Nutrition and water management on light soils. (Stanthorpe growers.)

5.4.7 Observations and comments made to reviewers by growers

Grower 1

- Agrees on new structure that has IAC and three working groups setting priorities for registered service providers to undertake research.
- His concern is the pipeline from industry problems at farm-gate level getting fed into the working groups and IAC. His suggestion is: regional-based IDOs reporting to AusVeg, not State-based organisations.
- Green waste trials have not been applicable, as severe nutrient deficiencies have resulted.
- Green waste trials must use material that is locally available and at minimum cost.
- Poultry manure (composted) applied on Sandbelt country does result in a significant crop response. The questions asked by Paul are: “Is it a plant ‘boost’ or is it from increased water and nutrient holding?”
- Any levy-funded trials must be on a commercial growers’ property and the farmer must be on board and have inputs into the design and components.
- Any research must have commercial relevance.
- Weather stations should be supplied to assist in professionally scheduling irrigations to ensure water is not limited.

Grower 2

- Doesn’t value Government-based researchers. Concerned his levy dollars are not returning value. Commissions his own private research. Employs private agronomist.

Grower 3

- Government-based researchers slow to investigate green manure and bio-fumigants. Uses data collected during privately-funded overseas trips.

Grower 4

- Proved to themselves the value of composted manures. Concerned about Anthracnose.

Grower 5

- Concerned about slow reaction time from Government-based researchers. Keen to engage private business to investigate specific soil health issues.

Grower 6

- Very supportive of the Knoxfield soil health program.

Grower 7

- “Most interested in our soils”, as soils are the backbone of the vegetable industry. Compares old days of growing beans, peas and sweet corn for the frozen food industry processors, when soils were heavily compacted, to now with fresh vegetables and the aim to minimise soil compaction and improve soil health and structure.

Grower 8

- When dealing with a lettuce monoculture, advocates a summer and winter green manure/bio-fumigant crop rotation or 1 in 3-year crop rotation.

Grower 9

- Advocates GPS, permanent beds, avoiding compaction, using high summer temperatures for solarisation, using gypsum to correct calcium/magnesium imbalance, and knowing what micro-nutrients are required.

5.5 Conclusions from the growers' survey

The grower survey identified three very clear messages about soil health research and extension.

- Soil health research should continue.
- The research should have a strong regional focus and produce outcomes on soil health, productivity and profitability that fit production systems.
- There needs to be effective communication of research results back to growers.

Growers understand soil texture (soil type), structure, pH, nutrients and soil organic matter but have limited understanding of subsoils, cation exchange capacity/nutrient-holding capacity and soil biology. There has been a high adoption rate of green manure crops (incorporated); composted manures; biological activators and soil testing, but limited uptake of controlled traffic and minimum tillage.

Lack of information and uncertainly about the effects on soil health and/or profitability currently stop nearly half of all growers from implementing improved soil managements practices. If growers are convinced of benefits however, they are willing to change.

Australia vegetable growers would like to improve their knowledge in the following areas:

- Soil biology and microorganisms
- Soil-borne disease control
- Interpretation of soil test results
- Biofumigation / alternatives to metham sodium
- Fertilizers and nutrition

Soil health research and extension efforts should be directed into the following areas, in order of priority:

1. Soil-borne diseases.
2. Biofumigation.
3. Nutrition, especially in relation to organic composts.
4. Soil biology – organic supplements and microbial activators.
5. Controlled traffic and no-till to reduce input costs and improve soils.
6. Soil health – general.
7. Organic composts and green manure crops, which are being widely used.

6 Analysis

6.1 What has been taken up by industry – what has worked?

The following areas were identified in the grower survey as being useful outcomes of the HAL soil health program and other cross-industry soil health RD&E activities.

1. **High level of engagement with the soil health programme**: There is a very high level of engagement with soil health projects, attendance at field days, use of factsheets, newsletters, VegeNotes and articles in industry magazines. There is strong support among growers for soil health research to continue in the Australian vegetable industry.

2. **Adoption of cover crops and organic supplements**: There has been a very high adoption of green manure crops (incorporated), composted manures and biological activators, but a very low level of understanding about soil biological processes after the organic matter has been incorporated into the soil.

3. **Good knowledge of soil physical and chemical properties**: There is a high level of awareness about texture (soil type), structure, pH, nutrients and soil organic matter.

4. **High usage of soil testing**: A very high proportion of growers (98%) use soil testing to measure soil nutrient levels and to monitor changes in soils over time. Growers rely heavily either on consultants or their own interpretations for making decisions on the information contained in soil test reports.

5. **Willingness of growers to change**: More than 90% of farmers said they have successfully changed soil management practices to achieve better yields, control diseases, improve sustainability or increase financial returns.

6. **Communication preferences**: 43% of growers said they found specific communications from soil health projects either useful or very useful. The preferred forms of communication (in order of preference) were:

    1. Talking to other growers
    2. Consultants
    3. Field days or field walks
    4. Information via websites
    5. Training/workshops
    6. Printed factsheets
    7. Research project reports
    8. Video/YouTube presentations
    9. Audio presentations

More specifically, in relation to the HAL soil health program, successes include:

- There are now adequate general reference and information guides available on soil management for vegetable growers, for example: The Ute guide; the QDAFF Soil health manual; VegeNotes 7, 12, 18; Improving soil health for yielding profit in vegetables: soil health management guide (Vic DPI).

- Training workshops such as the HSSF soils awareness days, the VG06100 soil health information days and the VG07008 soil workshops and field days were all effective and valued by growers.

- The VegPASH Newsletters, the five Victorian DPI information leaflets, and the Victorian DPI Improving soil health for yielding profit in vegetables: soil health management guide were well regarded by growers. The VegeNotes series (7, 12, 18) were also cited as examples of targeted, effective communication.

- The Vegetables WA Good practice guide and newsletters were specifically mentioned by WA growers in the survey. Clearly these were effective communication tools.

6.2 Gaps and weaknesses: what has not worked?

1. **Gaps remain in growers' knowledge about soils**: There is a low level of awareness among vegetable growers about subsoils, cation exchange capacity/nutrient holding capacity and soil biology.

2. **Lack of specific information about soil management**: Lack of information or uncertainty about the impact on yield economics or the soil was given by 45% of growers as the main reason they don't change current practices. This suggests a large knowledge gap remains to be filled by effectively communicating soil health information to growers and consultants.

3. **Too much conventional cultivation**: In the vegetable industry there is still a very high level of conventional cultivation methods such as the rotary hoe used, and little use of controlled traffic and minimum tillage techniques.

4. **Communication problems**:
    - Twenty-eight per cent of growers claimed they had never heard of any output from any soil project, while 43% of growers said they found specific outputs of any soil health projects either useful or very useful. This suggests current communication methods are working with some growers, but not all.

    - Ute guide: The success of this is equivocal; those who use it love it, but 33% of growers did not know about it. It is perhaps more of a reference tool than a crop, soil and region-specific "how-to" guide.

5. **Poor soil test record keeping and interpretation skills**: There was heavy reliance on paper records and little on electronic storage and retrieval. Growers highly valued their own interpretations of soil test reports, but admitted to having a poor understanding of how to interpret soil test results.

6. **Low adoption of farm management software**: This was rated as useful by only 10% of growers, suggesting an opportunity to promote or develop more effective management tools in this area.

6.3 What the soil health programme has achieved from a scientific perspective

Vegetable soils have been characterised across all States and the soil properties documented. Additional research may be required to answer questions relating to specific crops and local issues. There is an adequate number of general soil reference publications on vegetable soil health available, either produced as part of the HAL soil health program or other soil-related RD&E activities. There is an unmet need for information on specific issues/crops/regions.

The following scientific outputs have been produced as part of the HAL soil heath program:

VG07008

- O'Halloran, N. et al. (2011) Organic amendments necessitate a trade-off between building soil organic carbon and supplying crop nitrogen. Acta Hort. (submitted)
- Porter, I.J. et al. (2011). Influence of soil organic matter on soil health, crop productivity and N2O emissions in vegetable crops. Acta Hort. (submitted)
- O'Halloran, N.; Fisher, P.; Aumann, C.; et al. (2010) Relationship between organic matter retention and soil carbon in irrigated mixed farming systems. Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010.
- Assessment of a user-friendly computer-based tool ('C-Calc') to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.
- 13 additional conference papers.
- Honours Thesis: Hanlon, L.M. (2010). Club root expression in Brassica crops in an organically amended horticultural soil. Honours thesis. University of Melbourne.
- Soil health management chart: benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries. Distributed to more than 300 growers at workshops.
- Improving soil health for yield and profit in vegetables: soil health management guide.
- Veggie notes issue 18.
- 5 Victorian DPI information leaflets

VG06100

- Heisswolf, S.; Wright, R.; Moody, P.; et al. (2010) Vegetable production in the dry tropics - nutrient and soil management strategies from Queensland Australia. Acta Horticulturae Issue: 852: 97-106
- The soil health manual Soil health for vegetable production in Australia
- VegeNote Issue 12: Indicators of soil health
- Four issues of the VegPASH project newsletter

The Ute Guide

- Healthy Soils for Sustainable Vegetable Farms: Ute Guide
- Instructional DVD
- A training manual linked to the ANTA: Certificate of Amenity Horticulture RTF03
- Soil Interpretation and Management courses

7 Recommendations

7.1 Industry-level issues

A key issue for industry leaders is: What is an appropriate distribution of tasks and responsibilities for soil management and assessment; between vegetable growers, agronomic consultants, soil management specialists and soil research scientists? Two initiatives that could help with this broad issue are the establishment of a national strategy for vegetable soil research, and a national soil benchmark database.

7.1.1 National strategy for coordinating vegetable soil research.

There should be a national strategy for managing vegetable soil RD&E activities. Such a strategy could benefit the Australian vegetable industry if researchers can engage with broader soil health research programs; possibly there could be a nationally co-ordinated effort across horticulture or even other cropping industries such as grains.

DAFF undertook a stock-take of soil research in 2011 and identified that $124 M was being spent annually on soil research in Australia. The stock-take is now being used to help develop a national, cross-sector soils RD&E strategy under the National Primary Industries RD&E framework. The soils RD&E strategy will explore opportunities to improve efficiency and effectiveness, and help to coordinate consideration of current and future soils RD&E needs across sectors.

There is an opportunity to leverage funding and expertise for soil research into vegetables or horticulture generally, by linking any vegetable soil RD&E with this broader national soil RD&E strategy. Information on the national soils RD&E strategy is available at: http://daff.gov.au/natural-resources/soils

7.1.2 National vegetable soil benchmark database.

There is no comprehensive soil benchmarking database for physical/chemical/biological health of topsoil and subsoil on Australian vegetable farms, in relation to soil requirements of the main vegetable crops.

7.1.3 Central repository for new vegetable-related soil research.

There is no national “central repository” for new soil-related R&D information. If such a repository were available, it would be of great interest to vegetable growers and their consultants.

One solution would be the appointment of a Soil Management Coordinator for the vegetable industry to undertake the collation of a database and also a research result repository, and to highlight knowledge gaps. A good starting point for such an exercise would be the NSW DPI ‘SOILpak for vegetable growers’ (http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/vegetable). The repository/database could take the form of an interactive website that receives regular updates from researchers and growers/consultants.

7.1.4 Industry soil assessment protocols.

The development of a soil benchmark database would provide a sound foundation for documenting specific soil x crop requirements, and also be a repository for new soil data generated by research. A requirement would be to develop widely-accepted 'industry soil assessment protocols', i.e. minimum standards for the collection of physical, chemical and biological data for topsoil and subsoil. Procedures for integrating this information with precision agriculture inputs (yield mapping, EM surveys) and crop requirements could also be included. For example, QDAFF currently uses one set of soil assessment criteria and Vic DPI uses another for assessing soil health, but both are based on the same Cornell University model.

7.1.5 Reporting of vegetable soil research.

While there is a need to produce accessible publications for growers and consultants, there is also a need to properly document research outcomes when they can add to the general knowledge about soils. The proper output for scientific research is to publish results in peer-reviewed scientific journals. Our suggestion regarding reporting is to minimize the effort of producing a HAL final report, and instead, develop effective communication materials for growers (see next section) and publish scientific results as peer-reviewed papers. Both forms of communication are accessible and can feed into a central repository / soil benchmark database, and the AusVeg register for vegetable R&D outputs. The following papers are examples of well-reported vegetable soil research: (Wells, Chan et al. 2000, Chan, Dorahy et al. 2007, Chan, Dorahy et al. 2008, Chan, Wells et al. 2010).

7.2 Guidelines for future projects: the research gaps

7.2.1 The future of soil health research for the Australian vegetable industry

The following messages came through very clearly from the growers interviewed as part of the soil health survey.

1. Soil health research should continue.
2. Projects should be smaller, with a strong regional and technical focus, specific enough to provide useful solutions to growers for their soil type, climate and crops, i.e. projects should aim to solve specific problems on a regional basis.
3. Results of the projects must be effectively communicated back to growers.
4. Projects should develop outcomes that fit into production systems, with impacts on soil health, productivity and economics communicated to growers.

7.2.2 Priority areas for research, development and extension

Australian vegetable growers identified the following RD&E issues, in order of priority:

- Soil-borne diseases.

- Biofumigation.
- Nutrition, especially in relation to organic composts.
- Soil biology – organic supplements and microbial activators.
- Controlled traffic and no-till to reduce input costs and improve soils.
- Soil health – general.
- Organic composts and green manure crops, which are being widely used.

7.2.3 Communications:

1. Field days, workshops, newsletters and articles in grower magazines are highly valued and should continue.

2. The results of current and future research projects must be effectively communicated back to growers using the communication methods outlined above.

3. The soil knowledge-base for the vegetable industry needs to be improved by providing information, including results from past projects, to vegetable growers in an effective format. .

7.2.4 Skills and training

Vegetable growers rely heavily on consultants for advice, yet lack of information prevents 46% of growers from making changes/improvements to soil management. The heavy reliance on consultants suggests an evaluation of their skills and knowledge in soil assessment and management is warranted. If knowledge deficiencies are identified, investment in soil training for consultants is likely to have a high benefit-cost ratio. There also may be scope for high-calibre soil consultants working in other rural industries to be attracted to the vegetable industry. A paper by soil scientist Dr David McKenzie discusses how more effort needs to be devoted to the development of professional networks for dissemination and application of soil management information (McKenzie 2012).

The following areas were identified by growers as high priority for training:

- Soil biology and microorganisms.
- Soil-borne disease control.
- Interpretation of soil test results.
- Biofumigation / alternatives to metham sodium.
- Fertilizers and nutrition.
- Management of subsoils (testing, interpretation and management).
- Use of crop management software and electronic storage and retrieval of soil test results.

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9 Appendix 1: Other soil health research relevant to the Australian vegetable industry

The following section is a listing of other soil health research that has been undertaken over the past 19 years in Australia and is relevant to the Australian vegetable industry. The projects are not critically reviewed, and the intention of this section is to inform readers of this review of the existence of this work.

This section is not intended to be a complete review of all soil health-related projects over the past 20 years, but rather a snapshot of projects which may be of interest to growers, researchers and consultants working in the Australian vegetable industry.

9.1.1 Management of soil health for sustainable vegetable production

Year completed: 2007
Project number: VG06090
Funding agency: HAL and AusVeg

Synopsis: This project conducted a 12-month review of the temperate vegetable industry to assist Horticulture Australia and AusVeg develop a strategic direction for soil health research, development and extension over the next five years. The project consisted of State workshops, a literature review and demonstration trials to validate tools for benchmarking soil health. As a result of the project a Vegetable Soil Health Management Program for the next five years has been further developed by HAL in consultation with industry and leading research agencies. Keys to this program are that industry be engaged throughout the life of the program, the research program concentrate on the bottom line for growers and that a clear strategy be developed for greater adoption and evaluation of 'best practice' soil health management.

During this project, workshops conducted in South Australia, Tasmania and Victoria in 2007 determined that the key drivers to adopt good soil health management on-farm were to improve production efficiency by (1) more effective management of inputs (water, pesticides, fertilisers, organics); (2) improvements to soil structure and water use efficiency; and (3) sustainable disease control. Better management of these aspects of soil health were seen to improve yields, profit and product quality on farm, whilst minimising environmental costs and natural resource protection. Four key priorities were identified:

1. To measure and benchmark good farm practices for improved soil health.
2. To measure and understand the impact of crop rotations and tillage on soil structure, erosion and disease suppression.
3. To better manage organic inputs and organic carbon for improved soil health and water-use efficiency of soils.
4. To extend information that would drive adoption of "best practice" soil health management in two areas: management of biological and chemical inputs into farming systems; and management of physical inputs, especially tillage and water-use efficiency.

In addition, a literature review was also conducted that positioned Australia's soil health commitment in vegetables against soil health investment in other areas and industries.. A global shift in environmental funding toward soil health (after air and water quality), was identified, with key research already conducted in the cotton and grains industries in Australia. A willingness by the vegetable industry to participate in soil health activities is seen as a significant step towards future food security and environmental sustainability.

Finally, demonstration trials were conducted on properties of two key vegetable growers to test the rigour of more than 35 potential soil health indicators. Through these trials, a selection of chemical, biological and physical soil health indicators were identified for use in future research trials.

Contacts: Ian Porter, Victorian DPI.

9.1.2 A stocktake of Australia's current investment in soils research, development and extension: A snapshot for 2010-11

Year completed: 2011
Funding agency: DAFF

Synopsis: The Primary Industries Standing Committee is overseeing the development of a National Primary Industries Research, Development and Extension Framework to guide future research in fourteen industry and seven cross-industry sectors. The aim of the Framework is to ensure that Australia's approximately $1.6 billion annual RD&E investment in primary industries is focused and used efficiently, effectively and collaboratively. This stocktake provides some of the information needed for a proposal for a cross-sector soils RD&E strategy, which it is hoped, will become part of the Framework. The preparation of this report has been led by the Department of Agriculture, Fisheries and Forestry, with the support of a Soils RD& Working Group, which includes representation from most states/territories, CSIRO, the university sector and several rural research and development corporations.

One hundred and twenty stakeholder organisations were invited to provide information on their role, projects, funding, collaborators and human and physical resources, and views on the future for soils RD&E in their organisation. Detailed responses were received from 45 organisations and their data were used to assess investment in soils RD&E for 2010-11 across Australian, state and territory government agencies, tertiary education institutions and the private sector. This assessment was supplemented by information from surveys of consultants and individual soil scientists.

The Working Group identified the following opportunities for improving the effectiveness of soils RD&E:

- a cross sectoral soils RD&E co-investment process
- more collaborative use of the physical infrastructure
- an effective national soils data infrastructure, including a networked soils archive, better access to existing information and a national cooperative soil survey program
- agreed organisations' roles and responsibilities in the soils RD&E sector
- extension opportunities, especially more direct engagement with consultants
- an increase in training and education.

The findings of the stock take present a clear picture of significant RD&E activity that is complex and changing, but is in general, largely uncoordinated. Soils RD&E capability (FTEs) and research provider expenditure is substantially greater than for most primary industry sectors except grains. The Working Group noted the complexity of the soils RD&E sector and the sensitivity of funding arrangements to government budgetary pressures and changes in policies and programs. This sensitivity is all the more acute because soils RD&E is seen as enabling, rather than providing direct and immediately captured benefits to a particular industry or interest group.

Contacts: The full report is available on the DAFF website: http://www.daff.gov.au

9.1.3 The soil health knowledge bank

Year completed: 2008

Funding agency: Department of Agriculture, Fisheries and Forestry. The Grains Research and Development Corporation was a major co-funder and the Program was managed by Land & Water Australia.

Synopsis: The website is part of the Healthy Soils for Sustainable Farms Program. This website presents information that has in part been sourced from a number of existing websites and information delivery organisations. The intent was to consolidate the huge amount of technical and practical knowledge for the effective delivery of generic soil health information to end users, whilst providing direct links to regional or industry specific information. It has taken information from the following sources:

- The Department of Primary Industries Victoria (www.dpi.vic.gov.au/vro)
- The Department of Primary Industries and Fisheries Queensland (www.dpi.qld.gov.au)
- The Department of Primary Industries New South Wales (www.dpi.nsw.gov.au)
- The Department of Agriculture and Food Western Australia (www.agric.wa.gov.au)
- The Department of Primary Industries and Water Tasmania (www.tas.gov.au)
- Soil quality website: Western Australia (www.soilquality.org.au)
- Soil health website: Australian Soil Club (www.soilhealth.com.au)
- Bettersoils website: Agricultural Bureau of South Australia (www.bettersoils.com.au)
- The University of Western Australia (www.uwa.edu.au)
- Department of Primary Industries and Resources of South Australia (PIRSA; www.pir.sa.gov.au)
- CSIRO Australia (www.csiro.au)
- Land & Water Australia (www.lwa.gov.au)

The website has a number of sections as follows:

1. Definition of a healthy soil – list 6 characteristics
2. Tips for a healthy soil – 10 tips
3. Diagnose the health of a particular soil
4. Tips on maximising profits: soil diagnostics, a water use efficacy calculator and a carbon calculator as well as links to a range of external tools
5. Information for soil health: a great deal of background information on many aspects of soil health and functionality.
6. Case studies: a total of 53 case studies covering 15 soil topics

Contacts: The web address is: http://www.soilhealthknowledge.com.au/

9.1.4 Vegetable Industry Development Program: Soil Health

Funding agency: HAL

Synopsis: This is a six-page publication which includes: an explanation of soil health in terms of physical, chemical and biological aspects; why soil health is important: and coverage of some research such as the Ian Porter's soil health project. It discusses in brief terms how to assess soil health and provides some physical, chemical and biological threshold values. It also includes some case studies and references to soil publications such as the ute guide.

Contacts: The vegetable industry development program publication is available from the vegetables Victoria website www.vgavic.org.au/

9.1.5 The Australian Vegetable Industry Soil and Land Management Knowledge Exchange is a new and innovative tool for growers, researchers and industry representatives.

Year completed: 2011

Project number: VG07146

Funding agency: HAL

Synopsis: The Knowledge Exchange provides the primary target audience of growers and industry consultants with scientifically reviewed resources that are developed and presented in a language and manner that increases accessibility and promotes acceptance and adoption. It is a unique concept where soil and land management information, relevant to vegetable growers, will be harvested and then synthesised to give the audience a synopsis of the information. This is expected to assist growers when determining relevant information and deciding if they need to go further and in which direction. The information and tools harvested will be reviewed by a forum of industry stakeholders, scientists and professional editors to avoid duplication of material, verify appropriateness and ensure the information is scientifically sound. This site will be for the vegetable industry, and members of the vegetable industry will be able to submit and upload content they find and feel is useful - this content will also be reviewed by the Exchanges Forum panel prior to upload to once again ensure the quality and standard of material presented. The Knowledge Exchange has a life far in excess of the project (2011), but, requires ownership and participation of key stakeholders in identifying and uploading information. This provides industry the opportunity to actively participate in sourcing information and the design and content of the site.

Contacts: Jim Kelly, Arris Pty Ltd, info@arris.com.au

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

Year completed: 2003
Project number: VG99057
Funding agency: HAL and AusVeg

Synopsis: The study highlighted the 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 were:

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.

Contacts: Dr. Hoong Pung Peracto Phone 03 6423 2044

9.1.7 SOILpak for vegetable growers

Year completed: 2000

Funding agency: Natural Heritage Trust

Synopsis: This publication is designed to help vegetable growers and advisers make on-farm soil management decisions. Vegetables in New South Wales are grown on a wide range of soil types under varying production regimes.

This SOILpak targets the main soil groups used for vegetable growing and addresses the key soil management problems and strategies. Farmers seeking to make soil management decisions should use this manual in association with their local knowledge and information supplied by district horticultural advisers.

The vegetable SOILpak is in 6 parts and is available via the internet or as a printed version in looseleaf binder.

The sections covered by the guide are:

- Part A. Introduction
- Part B. Quick help
- Part C. Diagnosing soil condition
- Part D. Practical soil management: after the diagnosis
- Part E. Background information
- Appendixes

Contacts: The SOILpak guide can be viewed at:

(http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/vegetable),

9.1.8 EnviroVeg

Year completed: ongoing
Project number: various
Funding agency: Industry levies and HAL

Synopsis: EnviroVeg is the vegetable industry's own environmental program developed specifically for vegetable growers.

EnviroVeg provides growers with guidelines and information on how to manage their business in an environmentally-responsible manner. It provides a visible way of demonstrating a responsible attitude towards the environment. It also assists growers by showing the community that they are responsible environmental managers.

Growers achieving environmental certification may also benefit from a marketing edge. EnviroVeg is an industry-owned and developed environmental program for vegetable growers.

Aims of the program are for growers:

- To have their environmental practices recognised and acknowledged.
- To identify the farming practices that they already have in place which have a beneficial environmental impact.
- To demonstrate to the community that they are actively engaged in environmentally-responsible vegetable production.
- To get information from the program’s website and newsletters on useful sites, courses and information.
- To get information about any subsidies, grants or funding this is available to growers wishing to make environmental improvements on-farm.

The EnviroVeg program covers a range of environmental issues as they relate to vegetable production in Australia.

The program has a focus on healthy soils, promotes the Ute Guide, provides information on how to manage soil health, and runs training sessions around the country which include workshops, courses and course material on soil health. The AusVeg website has a tool which growers can use to assess the environmental performance of their farm.

Contacts: http://www.enviroveg.com

9.1.9 Vegetables WA – Good Practice Guide

Year completed: 2007

Project number:

Funding agency: the project was funded by the Australian and West Australian governments' investment in the Natural Heritage Trust administered in the Swan Region by the Swan Catchment Council.

Project team: David Anderson (chairman, vegetablesWA), Allan McKay (DAFWA), David Ellement (Industry Development Officer, VegetablesWA) and Kathryn McCarren, former VegetablesWA).

Synopsis: The Good Practice Guide has a strong focus on the particular requirements of the very sandy soils in the main vegetable growing areas in Western Australia. Its number of discrete sections include:

- Soil management
- Nutrient management
- Water management
- Pest and disease management
- Biodiversity, waste, air quality and energy
- Manures and crop residues
- Glossary and appendices

The soil management guide contains a lot of good information about managing soils with a strong focus on managing organic matter and organic supplements. It is a high-quality publication, with clear data and well designed.

The nutrient management guide is of similarly high quality and covers various ways to supply nutrients to crops, calculate application rates then monitor the crop and soil response to these interventions.

The manures and crop residues section is a brief document that essentially outlines the legislative requirements in relation to using manures on vegetables in WA.

Contacts: The guide and all the relevant sections are available on the vegetables WA website: http://www.vegetableswa.com.au/goodpractice.asp

9.1.10 Enhancing root and soil health in tomato and melon cropping systems.

Year completed: 2002 (final report)

Project number: VX99043

Funding agency: HAL

Synopsis: The project was terminated prematurely on 12 November 2001.

This project investigated the reasons for diminished root and soil health in tomato and melon cropping systems. The project consisted of two main research themes, including (1) the effects of organic amendments on the physical, chemical, and biological properties of the soil and the interaction with root disease organisms, and (2) assessment of a broad range of commercially available bio-additive products claimed to increase yield and improve soil health.

Field trials conducted at Bundaberg and Bowen showed that a yearly input of up to 34 tonnes of carbon per ha per year (in the form of sugar cane trash, a green manure crop, and/ or molasses), greatly augmented the soil microbial populations. However, the marketable yield of the tomato and melon crops was not increased, and in some seasons, decreased slightly. Molasses was shown to have a variable benefit in stimulating soil microbes. It was suspected that the yield depression from addition of the organic amendment treatments for some crops grown in the trials was due to a nitrogen (N) draw-down effect. The N draw-down in crops grown in soil to which organic matter is applied could be overcome by applying soluble N fertiliser through the trickle irrigation tubing in the first 2 weeks after transplanting or allowing a period of at least 13 weeks from incorporation to field planting. Studies of the effects of the organic matter treatments on tomato stem pathogens Fusarium spp. and Verticillium spp. (fungi capable of vascular invasion via the roots and in some cases may be pathogenic and cause wilt diseases depending on the species and strains involved) revealed inconclusive results.

Comprehensive testing of a broad range of commercially available bio-additive products (including E2001/ Multibacter, Trichogrow/ Trichoflow, various Nutri-Tech Solutions products, Humega/ SupaHumus, and Kelpak) showed that Kelpak was ranked in the top 2 treatments for weight of marketable fruit in 5 of the 6 trials. However, differences were only significant for the 2001 tomato trial at Bowen, and then only between Kelpak and Supa Humus. This lack of difference between treatments for the yield and quality parameters that were measured indicated that growers using these products would be unlikely to see any visible effects to the crop. Despite anecdotal evidence aplenty, the absence of comprehensive field studies on bio-additive products of the kind undertaken in this project can be explained by the quantity and meticulous nature of the work required to conduct such experiments. The fact that our team conducted the work at 2 geographically diverse sites makes the work even more extraordinary.

Contacts: Queensland Department of Agriculture, Fisheries and Forestry.

9.1.11 Use of garden organic compost in vegetable production under contrasting soil P

Year completed: 2007

Funding agency: NSW Department of Environment and Climate Change

Synopsis: Little research has been carried out on the agronomic value of compost produced from garden organics for vegetable production. A field experiment was established in Camden, near Sydney, Australia, to (i) evaluate the effect of the compost on vegetable production and soil quality relative to conventional practice, (ii) compare vegetable production under high and low soil P status, and (iii) monitor the changes in soil P concentration under two compost treatments relative to conventional farmers' practice. After three successive crops (broccoli, eggplant and cabbage), results indicate that compost (120 dry t/ha) and half-compost (60 dry t/ha supplemented by inorganic fertilisers) treatments can produce similar yield to the conventional practice of using a mixture of poultry manure and inorganic fertiliser. Furthermore, similar yields were achieved for three different crops grown under high and low P soil conditions, clearly demonstrating that the high extractable soil P concentrations currently found in the vegetable farms of Sydney are not necessary for maintaining productivity. The compost treatments also significantly increased soil organic carbon and soil quality including soil structural stability, exchangeable cations, and soil biological properties. Importantly, the compost treatment was effective in reducing the rate of accumulation of extractable soil P compared with the conventional vegetable farming practice. Our results highlight the potential for using compost produced from source separated garden organics in reversing the trend of soil degradation observed under current vegetable production, without sacrificing yield.

Contacts: Tony Wells tony.wells@dpi.nsw.gov.au or Yin Chan yin.chan@industry.nsw.gov.au

References:

Australian Journal of Agricultural Research, 2008, 59, 374–382
Australian Journal of Experimental Agriculture, 2007, 47, 1377–1382

9.1.12 Phosphorus accumulation and assessing P fertiliser use in soils used for vegetable production: agronomic and environmental implications.

Year completed: 2010

Funding agency: NSW Department of Environment, Climate Change and Water

Synopsis: Vegetable production is often located in the peri-urban areas close to large cities. In Sydney, Australia, excessive levels of phosphorus (P) have been reported in the soils, and vegetable farms have long been regarded as a potential source of the P that enters Sydney's waterways. We report vegetable production under varying soil P conditions and the consequent changes in soil P, as well as water quality of runoff and leachate after growing 5 crops in a field trial where inputs in the form of garden organic compost were compared to current farmers' practice. No difference in vegetable yield was observed between 100 and 400 mg/kg of soil Colwell P (0–0.10 m); therefore, our results indicate that the excessive soil P levels in the vegetable farms around Sydney are not important for optimal vegetable production. Results from runoff and leachate studies clearly demonstrate that high concentrations of P in soils used for vegetable production under the current farming practice around Sydney have increased the potential to export P and to negatively affect water quality of receiving environments. The significant increases in soluble P concentrations found in the soil and runoff water from the current farming practice can be attributed to the use of poultry litter. In contrast, using compost in place of poultry litter resulted in significantly reduced soil P accumulation and P concentration in runoff and leachate. Training and education programs for farmers and their advisors are recommended to encourage more sustainable fertiliser management practices and reduce the accumulation of P in the environment.

References:
Australian Journal of Soil Research, 2007, 45, 139–146
Australian Journal of Soil Research, 2010, 48, 674–681

Contacts: Yin Chan yin.chan@industry.nsw.gov.au or Simon Eldgridge
simon.eldridge@dpi.nsw.gov.au

9.1.13 Development of a sustainable integrated permanent bed system for vegetable crop production including sub-surface irrigation extension

Year completed: 2002
Project number: VG 98050
Funding agency: HAL (HRDC)

Synopsis: Conventional tillage practices in vegetable production break up the natural soil aggregates and cause a decline in the levels of soil organic matter that binds the soil particles together. This loss of organic matter over time leads to a decline in soil structure and problems such as soil erosion, surface crusting, the formation of hardpans, and poor infiltration.

The bed system developed through this research uses permanent beds that are sown with a cover crop. The cover crop is then killed when sufficient biomass has been produced and the residues are left on the bed surface, resulting in improved soil structure over time. Crops are then transplanted through the residues, which form an organic mulch that suppresses weeds and retains moisture within the soil.

The retention of an organic mulch on the soil surface and a reduction in cultivation results in an increase in active organic matter within the soil. This promotes improvements in soil physical and biological properties and crop productivity. Worm populations increased from 0 per m^3 of topsoil under conventional practices to a maximum of 8000 per m^3 in the permanent-bed system.

The stability of soil aggregates has improved significantly with aggregates in the permanent-bed system rating 3 out of 4 for stability compared to a rating of 1 for the soil aggregates sampled from the conventional production areas, resulting in a more friable, less compacted soil with a lower soil bulk density relative to conventional cultivation and plastic mulch.

Conventional tomato production produced higher yields in the first four picks than production on the permanent beds, but the crops on permanent beds had a higher yield after the first four picks. Total yields are similar between the two systems, but are delayed where organic mulch is used instead of black plastic.

Capsicum, eggplant, rockmelon, pumpkin, honeydew, broccoli and ground tomatoes were also grown in experimental plots using the permanent-bed system, all of which were grown to harvest without any growth suppression. There can be an increase in Damping off diseases in seedlings transplanted through mulch, but this seems to be more of an issue when planting into fresh mulch residues. Improvements in soil structure mean: more air and moisture can be held within the soil; crop roots can move through the soil and establish faster; high levels of rainfall are rapidly drained away allowing earlier vehicular access to production areas; and soils are less prone to erosion in all conditions. A healthy well-structured soil is vital to the continued productivity of horticultural systems.

Contacts: Gordon Rogers, AHR gordon@ahr.com.au

9.1.14 Comparison of conventional and alternative vegetable farming systems on the properties of a yellow earth in New South Wales.

Year completed: 1999

Funding agency: HAL (HRDC)

Synopsis: Intensive vegetable farming has the potential to damage soil health, leading to poor productivity and large environmental impacts. This paper reports on changes in soil properties after three and a half years of vegetable cropping and discusses the implications for sustainability. A vegetable farming-systems experiment began in 1992 at Somersby, in NSW, Australia. The aim of the experiment was to compare five different approaches to vegetable cropping in terms of their productivity, profitability, soil effects and environmental impact. The experimental treatments represent whole production systems, intended to simulate real farms, but under more controlled conditions than is possible on farms.

The systems are defined by the goals and values of the farmer rather than by the management practices employed. The actual management practices — nutrition, tillage, rotations, pest and weed management, etc. — were selected to satisfy these goals and values. For instance, to satisfy the goal of 'maximise profit', fertilisers and pesticides were applied in excess to ensure high yields of large, undamaged produce which receive the best prices. Conversely, one of the management practices used to satisfy the goal 'optimise profit while minimising environmental impact' was to grow cover crops regularly in rotation with vegetable crops.

A range of chemical, physical and biological properties of surface soil (0–10 cm) from the farming-systems were measured and compared to baseline measurements. The two alternative systems, which received large inputs of compost, had higher soil organic carbon, microbial biomass, total nitrogen, total phosphorus, exchangeable nutrient cations, water-holding capacity and aggregate stability than the conventional systems. The system that received the largest mineral fertiliser inputs, and the most tillage, had the highest available phosphorus levels, the lowest phosphorus sorption capacity and lower aggregate stability than the alternative systems.

Consequently this high input system had the greatest potential to lose sediments and phosphorus to the environment. The two other conventional systems had smaller fertiliser inputs and maintained a phosphorus sorption capacity that was no different from the alternative systems. These more carefully managed conventional systems offer hope that relatively small changes in management can have significant environmental benefits. Yet the broad improvement in soil health achieved by the biological approaches should provide better long-term fertility and lower off-site impacts. It may be wise to make use of both these approaches to management in attempting to balance the short and long-term viability of intensive vegetable farming

Contacts: Tony Wells tony.wells@dpi.nsw.gov.au
Reference: Agriculture, Ecosystems and Environment 80 (2000) 47–60

9.1.15 Project VG07035 Investigation of yield and soil variation in sweet corn

Year completed: 2000

Funding agency: HAL and AusVeg

Synopsis: Crop growth parameters were monitored during the season and yield and quality parameters at harvest. Five fields planted with two varieties of Sweet corn were intended to be monitored at The Lagoon, near Bathurst. However, different sowing dates created problems with mid-season sampling and crop biomass data collection and the focus changed to one variety (Punch) at harvest, with mid-season tissue N analysis also confined to this variety.

Two soil sensors and a carrier-phase GPS receiver collected high resolution spatial data on soil and topographic variation to provide information on the electrical conductivity (ECa) of the soil. A vehicle mounted crop biomass sensor collected information that was geo-referenced with a Garmin GPS76 GPS receiver. A 4-band multi-spectral aerial image was taken of the 5 fields and registered with ground control points gathered by the ECa sensors.

Manual field sampling was also conducted with soil cores extracted to a depth of 1m. The soil core locations were geo-referenced with the Omnistar HPGPS.

Contacts: Brett Whelan, Australian Centre for Precision Agriculture NSW, University of Sydney, 02 9351 2222

9.1.16 Nutrients: Best Practice for Sustainable Land Use in the Northern Territory

Year completed: 2008

Funding agency: National Landcare Program (NLP) through the Commonwealth Department of Agriculture, Fisheries and Forestry (DAFF)

Synopsis: The NT Sustainable Land Use Guidelines were a product of the "Best Practice for Sustainable Land Use in the NT" project which was conducted from 2005-2008. This project was a co-operative venture between the NT Horticultural Association (NTHA) and the NT Agricultural Association (NTAgA).

The project was a collaborative effort by stakeholders in the NT Horticultural and Agricultural Industries, including growers, researchers, extension/regulatory officers, NGOs and educators. It is a non-regulatory set of generic guidelines designed to provide land managers with a means of self-assessing their practices against Industry "best practice". It also enables land managers to work towards developing environmental management plans for their enterprises and will assist with attaining environmental accreditation for sustainably grown produce.

The guidelines are comprised of an introduction booklet termed Sustainable Agriculture and 13 key area booklets covering land management issues identified by stakeholders during the project. The 13 key areas include booklets one on soils and one on crop nutrition.

Another more compact format is the "Checklist Booklet" comprised of the 13 key area checklists and a CD containing the detailed background information for the key area booklets. This format and the hardcopy folder are available for purchase at the NTHA.

Contacts: NTHA office (08 8983 3233).

9.1.17 Healthy soils for sustainable farms – Overall program

Year completed: 2008

Funding agency: Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) and Grains Research & Development Corporation (GRDC), managed by Land and Water Australia.

Synopsis: The HSSF Program brought together industry groups, government agencies, research organisations, grower groups, farm advisors, extension officers, natural resource management (NRM) staff and catchment authorities, to collaborate in a series of projects across major agricultural regions. The projects aimed to encourage farmers, industry and the community to better understand and manage their soil resources, with this effort leading to the development and uptake of best management practices (BMPs) and soil management tools. The HSSF Program investment strategy focused on raising awareness, communicating management principles for healthy soils, providing measurement and assessment tools, demonstrating results, and providing guides and materials for education and training courses. It is conservatively estimated that the HSSF Program had contact with at least 30,000 people, providing general information about healthy soils and their benefits, as well as providing specific information for local commodity-based rural industries and communities. Over 17,000 farmers, advisors, extension and NRM staff were involved in at least one HSSF activity, such as education and training workshops, practical field demonstrations, soil assessment training, seminars and field days. The HSSF Program has developed a large legacy in the form of locally-relevant soil health guides, soil assessment tools and best management practices, new soil health indicators, local or regional soil assessment programs, education and training materials (some registered for National Training Information Service accreditation), and a web-based Soil Health Knowledge Bank that provides a national entry point and links to more detailed knowledge about soil management.

The HSSF Program achieved high participation rates, uncovered significant demand for information about soil health, and successfully delivered a range of products, workshops and forums. This was achieved despite difficult drought conditions. The HSSF Program produced new guides about the key principles of healthy soil management that brought together and collated knowledge that was formerly scattered and difficult to access. The HSSF Program also developed and demonstrated new methods for assessing soil health, including aspects of soil biology, and new soil health indicators. Soil health demonstration sites were established in many agricultural regions and will continue beyond the end of the Program, and its many legacy products will underpin continued education and training in managing for healthy soils.

There were a number of projects within the HSSF program:

- Healthy soils for sustainable vegetable farms (the ute guide)
- A Healthy Soils module for the Making More From Sheep publication
- Delivering workshops on low input farming approaches to soil health management for landholders in southeast Queensland
- Accelerating adoption of integrated soil management practices in irrigated cotton and grain
- Managing Landscapes — matching soils, climate and enterprises
- Accounting for nutrients on Australian dairy farms [A4N]
- Sustainable farming practices in the mid-Loddon sub-catchment
- Sustainable soil health management workshops for northern broadacre cropping industries

- Identify farm management practices that promote healthy soils and investigate the use of a soil health index to monitor changes in soil health
- Defining and promoting soil health for sustainable production systems
- Improving soil health in Western Australian farming systems
- Soil Health — leaving a legacy for southeastern Australia for the Healthy Soils for Sustainable Farms Program

Contacts: There is more information about each of these projects as well as resources produced in the HSSF Final report which is available on the Land and Water Australia website at http://lwa.gov.au/programs/healthy-soils-sustainable-farms

9.1.18 Victorian Soil Health Strategy: Protecting soil health for environmental values on public and private land

Year completed: 2012

Synopsis: The strategy is a broad soil health strategy covering horticulture, agriculture and the natural environment. It is not restricted to vegetable farming operations, however any decisions made in relation to soil health research in Victoria would presumably have to comply with this strategy.

To date, Victoria has lacked a clear statement of soil health management objectives to improve environmental and catchment conditions, in addition to productive benefits.

- This DSE Soil Health Strategy aims to address this need, and is intended to:
- Support work conducted by DSE, CMAs and DPI when planning and managing for the environmental benefits of soil health.
- Provide a framework for regional and local planning and delivery of soil health in Victoria, including the development of Regional Catchment Strategies (RCSs) that articulate a state wide soil health story
- Set priorities that allow Commonwealth, state, regional and local soil health investment to develop more effective and efficient soil research, development and extension projects which are of benefit to Victoria.

Other strategies will also help to address this lack of clear direction for soil health management, including the DSE-DPI Integrated Soil Health Management Framework.

Scope of the strategy: The continued prosperity of the natural environment in Victoria and its primary industries depend on the health of soils. The approach and goals set out in this strategy apply to all government-sponsored soil health management within Victoria. This strategy highlights the need to continue to address soil health issues where soils present a threat to public assets like rivers lakes and estuaries, but to also focus on protecting and improving soils as a valuable asset for the provision of all ecosystem services. This broader focus also means that soil management on both public and private land falls within the scope of this strategy.

Contacts: The strategy document is available from the Department of Sustainability and Environment website http://www.dse.vic.gov.au

9.1.19 Quantifying the benefits of recycled organics in agricultural cropping systems.

Year completed: 2005-2009

Funding agency: Department of Environment and Climate Change

Synopsis: This project is focussed on the Centre for Recycled Organics in Agriculture (CROA) site at Camden, a 32ha site 60 km south west of Sydney. CROA can demonstrate the benefits of using recycled organics (RO) over the long term.

This four-year project, aimed to quantify the agronomic, soil and environmental benefits of using composted garden organics (CGO) in agricultural cropping systems in NSW. The first phase of the project involved identifying which markets have the greatest potential to consume CGO products. This study identified that vegetable growing areas within the Sydney Basin could benefit from soil conditioners made from CGO, whilst wine producing areas in the Hunter Valley and Central West NSW could be good markets for CGO mulches.

The next phase of the project involved establishing an experiment at CROA, as well as field trials in vineyards in Central West NSW, to quantify the respective benefits of CGO soil conditioner and mulch on crop productivity and soil physical, chemical and biological characteristics.

The first crop, broccoli, was harvested in August 2005 with the second crop, eggplant planted in November 2005. The third crop, Red Cabbage was planted in May 2006, whilst the fourth crop, capsicum, was planted in December 2006. The fifth and final crop, leek, was planted in June 2007.

Mulch was also applied to vines in Central West NSW in time for the 2005/06 grape growing season. These sites are being monitored for a range of agronomic and soil parameters. Other components of the project included analysing compost samples from processors, collecting soil samples from vegetable farms within the Sydney Basin and vineyards in the Hunter Valley and Central West, as well as performing pot trials to evaluate compost performance.

Contacts: Simon Eldgridge simon.eldridge@dpi.nsw.gov.au

9.1.20 Australian and New Zealand Biochar Researchers Network

Synopsis: The Australian and New Zealand Biochar Researchers Network is a collaborative group of scientists interested in advancing the understanding and application of biochar materials. Collectively our aim is to collaborate on research programs, promote and advocate the adoption of biochar investigation and use, and communicate the opportunities presented by biochar to policy makers, land managers, the public, industry and fellow scientists.

The Network aims to provide a forum that brings together biochar researchers and practitioners from Australia and New Zealand. The Network is dedicated to all facets of biochar research, including soil productivity enhancement, carbon sequestration, waste management, risk assessment and environmental management, sustainability of feedstock supply, greenhouse gas mitigation and bioenergy co-production. Our focus is centred on biochar research in the Australian and New Zealand context; however, we also engage in and encourage broader international collaboration.

The Network recommends the use of biochars made from sustainably harvested and renewable biomass resources. The use of biomass for the production of biochar should not diminish essential environmental services, such as maintenance of water and air quality, protection of soil resources, and conservation of biodiversity. Biochar research should focus on biochar applications that deliver a net environmental benefit.

A number of studies have been conducted where biochar application has shown significant agronomic benefits. However, these results are not universal as other studies have shown no difference, or even some decline, in productivity. The reason lies in the wide range of properties between different biochars, and variation in impact due to interaction with different soil types. Our incomplete understanding of the processes that occur when biochar is applied to soil limits our ability to predict agronomic impacts of biochars in different situations.

Contacts: info@anzbiochar.org

1.1 List of all soil health project reports and outputs from AusVeg

Project No.	Type	Disciplines	Date	Title of project	Description
VG08043	Research report	Soil Health	2012	Development of methods to monitor and control Aphanomyces root rot and black root rot of beans	Developing a DNA-soil test to identify and monitor two soil-borne fungal diseases
MT09097	Research report	Soil Health, Productivity	2011	Effect of using reclaimed water on soil health and crop sustainability	This report presents results of investigations to assess the use of reclaimed irrigation water on soil health and crop sustainability in the Northern Adelaide Plains.
PT07038	Research report	Soil Health	2011	Identifying microbial communities in disease suppressive soils as means of improving root health of potatoes	The report details research using chaperonin gene technology from the medical field to characterise the consortia of soil microbes associated with two potato cultivars and two potato growing soils in Canada.
VG07146	Research report	Communication, Soil Health	2011	Australian Vegetable Industry Soil and Land Management Knowledge Exchange	This project has been developed as a tool for growers, researchers, and industry representatives - one of the largest specialised industry-based soil and land system sites in the world.
PT08046	Research report	Pest management, Soil Health, Productivity	2010	Development of a soil borne pathogen testing service for the fresh market industry	The project aimed to establish a soil sampling protocol for black dot in commercial fields using molecular based technology and develop a disease risk rating system that would provide a reasonable basis for disease prediction on a commercial scale.
VG07008	Research report	Soil Health, Productivity	2010	Benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries	This project aims to promote soil health practices that have both environmental and economic benefits to growers.
VG07125	Research report	Integrated Pest Management (IPM), Soil Health	2010	Best Practice IPM Strategies for Control of Major Soilborne Diseases of Vegetable Crops throughout Australia	This project has developed products to prevent infection or induce systemic acquired resistance with vegetables. It has also provided dramatic reductions (of up to 98%) in the impact of soilborne diseases in vegetable cropping systems using non-chemical control strategies such as crop rotation and grafting.

Project No.	Type	Disciplines	Date	Title of project	Description
VG07126	Research report	Soil Health	2010	Integrated management of soilborne pathogens (Sclerotinia beans, lettuce, carrots, celery and other)	This project was undertaken to develop a package of effective and economical control measures for most important soilborne diseases.
PT08048	Research report	Soil Health, Pest management	2009	Pilot project - Diagnostic tests for soilborne pathogens, International collaboration	Study undertaken to determine if tests to quantify pathogens in soil can be used as risk management tools for growers in the UK and Australia
VG06100	Research report	Soil Health	2009	Vegetable Plant And Soil Health	Understanding and managing soil health
PT04001	Research report	Productivity, Soil Health	2008	Understanding The Implications Of Pastures On The Management Of Soilborne Diseases Of Seed Potatoes	Study of the effects of different pasture species to minimise seed potato diseases
VG06090	Research report	Soil Health	2008	Management Of Soil Health For Sustainable Vegetable Production	Improvement of soil health and crop management on-farm
PT96020	Research report	Soil Health, Plant diseases	2007	Mechanisms Of Cadmium Accumulation By Potato Tubers (Cont'd PT620)	Analysing cadmium accumulation and factors for the differences in accumulation and examining the cadmium movement pathways
VG05005	Research report	Soil Health, Productivity	2006	Scoping Study To Determine The Soil Borne Diseases Affecting Brassica Crops	Investigating soilborne diseases in brassica crops and canker
PT01008	Research report	Pest management, Soil Health	2005	Monitoring And Developing Management Strategies For Soil Insect Pests Of Potatoes	Improving the capability of growers or their crop consultants by minimising or eliminating the damage to crops by soil insects
PT01019	Research report	Soil Health, Plant diseases	2005	Prediction And Molecular Detection Of Soil-Borne Pathogens Of Potato	Development of DNA-based soil diagnostic tests for pathogens within soil that cause diseases in potato crops
VG99016	Research report	Soil Health	2005	Identifying The Benefits Of Composted Soil Amendments To Vegetable Production	Evaluating the benefits of compost on vegetable production
PT99057	Research report	Soil Health, Environmental management	2004	Nitrogen Dynamics In Commercial Seed Potato Crops And Its Effect On Seed Yield, Quality, Storage And Subsequent Commercial Crop	Developing on-site Nitrogen monitoring using 'real time' monitoring tools

Project No.	Type	Disciplines	Date	Title of project	Description
				Performance	
VG02121	Research report	Productivity, Soil Health	2004	Scoping Study For The Management Of Oxalis In Horticultural Cropping Regions	Management of Oxalis Latifolia using soil fumigants and pre-emergent herbicides
VG98123	Research report	Soil Health	2004	Bark Residue As A Soil Amendment In Broadacre Intensive Vegetable Production	Improving soil structure in intensely cultivated agricultural soils
VX00013	Research report	Soil Health, Productivity	2004	Biofumigation - Optimising Biotoxic Brassica Rotations For Soil-Borne Pest And Disease Management	Developing alternatives to manage soil pests and diseases
PT96032	Research report	Soil Health, Crop Management	2003	Influence Of Rotation And Biofumigation On Soil-Borne Diseases Of Potatoes	Examination of the effects of crop rotation practices and biofumigation on the soil-borne diseases of potatoes
VG98140	Research report	Plant diseases, Soil Health	2003	Options For Managing Onion White Rot	Developing practical applications to reduce soil pathogen populations
VG99057	Research report	Soil Health	2003	A Survey Approach To Investigate The Soil Factors Associated With The Productivity And Sustainability Of Vegetable Production In Australia	Compiling soil health data to better understand their impact on crop yields
VX99029	Research report	Soil Health	2003	Monitoring And Diagnostic Aids For Predicting And Managing Soil-Borne Diseases In Fresh Tomatoes	Improvement of the monitoring and diagnostic aids for growers
PT97003	Research report	Environmental management, Productivity, Soil Health	2002	More Economically And Environmentally Responsible Use Of Phosphorus Fertiliser In Potato Cropping On Krasnozem Soils In Australia	Analysing the effects of reduced Phosphorus applications in potato crops
VX99043	Research report	Soil Health	2002	Enhancing Root And Soil Health In Tomato And Melon Cropping Systems	Investigating the causes for diminished soil and root health in tomato and melon crop systems

Project No.	Type	Disciplines	Date	Title of project	Description
PT97004	Research report	Soil Health	2001	Potato Pink Rot Control In Field And Storage	Control of potato pink rot disease in laboratory, glasshouse, and field experiments
PT00423	Research report	Soil Health, Fertilizers, Environmental management	2000	A National Strategy To Reduce Cadmium In Potatoes	Development of techniques to control cadmium accumulation in Potato tubers
PT00447	Research report	Soil Health, Crop Management, Pest management	2000	Integrated Management With Biofumigation To Control Soil Pests And Diseases In Potatoes	Development of alternate strategies for sustainable management of soil pests/diseases in horticulture
PT97026	Research report	Environmental management, Soil Health, Irrigation	2000	Developing Soil And Water Management Systems For Potato Production On Sandy Soils In Australia	Development of new methods of deep tillage for potato production in sandy compacting soils
VG00418	Research report	Plant diseases, Soil Health	2000	An Investigation Of Ascochyta And Related Diseases In Processing Peas	Investigating the diseases in processing peas
VG96033	Research report	Soil Health, Integrated Pest Management (IPM)	2000	Management Of Soil-Borne Pathogens In Vegetable Cropping Systems In Bundaberg, Queensland	Investigating the efficacy of alternative fumigants
PT00012	Research report	Soil Health, Productivity	1997	Soil Fertility Management In Potatoes On The Atherton Tablelands	This project was completed on the Atherton Tableland which was designed to find out if additional fertilisers were needed to increase the yield of potatoes and subsequent rotational crops.
PT00315	Research report	Varietal development, Soil Health	1997	Rhizoctonia Control On Fresh Market Potatoes	This project aimed to improve potato skin quality by controlling R. Solani and other major soilborne fungal diseases in Australia.

Project No.	Type	Disciplines	Date	Title of project	Description
VG00011	Research report	Soil Health	1997	The Reduction Of Cadmium Contamination In Tasmanian Vegetables And Poppies	This project determined the extent of cadmium impurities in Tasmanian vegetables and poppies and experimented with ways of decreasing cadmium (Cd) in crops or areas found to have unacceptably high concentrations.
VG00534	Research report	Soil Health, Productivity	1997	Nitrogen Nutrition In Onions	This project undertook three trials on the Krasnozem soils in 1995/96 investigating the effect of nitrogen topdressing on the yield and quality of onions.
VG00006	Research report	Fertilizers, Soil Health	1996	Effect Of Soil Conditions And Fertilizers On Cadmium In Vegetables - A National Approach	This project investigated the effect of farm management practices within a national perspective, on cadmium concentrations in vegetables, especially potatoes.
PT00006	Research report	Soil Health, Varietal development, Plant diseases	1993	Rapid Identification Of Streptomyces Spp. On Potato, The Key To Integrated Management Of Common Scab	Development of a rapid identification for potato scab and techniques to detect pathogens within soils causing disease
VG09038	Research report	Soil Health		Vegetable soil health systems for overcoming limitations causing soilborne diseases	This project offers an increased knowledge of the soil mechanisms and organisms that are involved in disease suppression and increased awareness of how different management practices impact on soilborne diseases of vegetable crops.
TL00205	Manual	Soil Health, Productivity	2010	Soil health for vegetable production in Australia	This 45-page, full colour manual takes a holistic view of soil health, considering the interaction of physical, chemical and biological soil properties. The balance and stability of these components are what make a healthy soil.
TL00191	Fact sheet	Soil Health, Fertilizers, Integrated Pest Management (IPM)	2010	Improving Soil Health for Yield and Profit in Vegetables	This 4-page fact sheet, produced by the VIC DPI Vegetable Soil Health Team, summarises the key findings of project VG07008. The researchers found that a range of different soil health practices have both environmental and economic benefits to growers.

Project No.	Type	Disciplines	Date	Title of project	Description
TL00193	Fact sheet	Plant diseases, Integrated Pest Management (IPM), Soil Health	2010	Managing Soilborne Diseases in Vegetables	This 4-page fact sheet, produced as part of the IPM Vegetable Disease Program, reports on the findings of project VG07125. The researchers from VIC DPI, Qld DEEDI and Peracto have found that green manures and Brassica biofumigant crops provide many benefits within vegetable cropping systems, which is assisting with the development of new strategies for managing soil-borne diseases.
VN00018	Fact sheet	Irrigation, Soil Health	2010	Water Use Efficiency and Soil Health Management shows Economic and Environmental Benefits	A 4-page factsheet that provides interpretation and training in the use of soil moisture data and discusses how proper soil health management shows economic and environmental benefits.
VN00019	Fact sheet	Integrated Pest Management (IPM), Productivity, Irrigation, Soil Health	2010	Development of Effective Pesticide Strategies Compatible with IPM Management used on Farm and Optimising Water and Nutrient Use on Vegetable Farms	This factsheet discusses how an expert think-tank has helped to fill the information gaps about the effects of fungicides on Integrated Pest Management (IPM) techniques. It also details how vegetable growers in Western Australia's Swan Coastal Plain are learning how to tailor their irrigation and fertiliser schedules in order to enhance crop quality and reduce budget and environmental pressures.
VN00012	Fact sheet	Soil Health, Nutrition, Crop Management	2009	Indicators of Soil Health	Factsheet detailing the indicators of soil health and effective methods to increase their nutrient levels to contribute to the overall health of crops.
TL00146	Fact sheet	Integrated Pest Management (IPM), Environmental management, Biodiversity, Soil Health	2008	Organic vegetable production - managing pests and diseases	This 8-page fact sheet describes the effective ways of managing pests (including weeds) and diseases in organic vegetable production systems. Many of the practices are applicable to integrated pest management (IPM), which is the use of integrated practices to manage any kind of pest including weeds and diseases. Organic pest management practices essentially involve the use of IPM without the use of synthetic chemicals.

Project No.	Type	Disciplines	Date	Title of project	Description
TL00252	Fact sheet	Soil Health	2008	Compost for managing salinity	This fact sheet provides an overview on compost for managing salinity, managing sodic soils, and managing saline soils.
TL00323	Fact sheet	Productivity, Soil Health, Fertilizers	2008	More efficient fertiliser use lifts gross margins	This fact sheet details how by adjusting fertiliser application rates to better match the yield potential of their soils, grain growers can reap substantial financial gains.
VN00007	Fact sheet	Environmental management, Productivity, Soil Health	2008	Healthy Soil Management	Factsheet that details the importance of management of soil to ensure the economic and environmental sustainability of vegetable production. Good soil management practices directly impact both on- and off-farm.
TL00028	Fact sheet	Fertilizers, Soil Health, Productivity	2007	Optimising phosphorus fertiliser use on intensively managed pastures	The factsheet demonstrates the lack of pasture dry matter response to applied fertiliser P on soils with high soil test P values.
TL00041	Fact sheet	Nutrition, Soil Health, Fertilizers, Crop Management, Productivity	2007	Tissue testing for phosphorus	This factsheet discusses the role of tissue testing for phosphorus in annual plants, including timing of fertiliser application.
TL00322	Fact sheet	Soil Health, Nutrition	2007	Nutrients applied to potato crops from irrigation water	This fact sheet details information on nutrients that are applied to potato crops from irrigation water. It includes content on how much nutrient can be applied from irrigation water and determining the amount of water applied and water sampling.
VN00003	Fact sheet	Productivity, Soil Health	2007	Composting On-farm	Factsheet that describes the use of compost as a soil conditioner to revitalise soil structure, texture and water-retaining capacity.

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TL00021	Fact sheet	Soil Health, Productivity, Environmental management, Fertilizers, Crop Management	2006	Free-living bacteria lift soil nitrogen supply	This article shows that there is a wealth of free-living bacteria in soils across Australia that are capable of fixing significant atmospheric nitrogen in the absence of legumes, using crop residues and root exudates as an energy source.
TL00040	Fact sheet	Soil Health, Chemical residues	2006	Testing soils for residues of persistent chemicals	This primefact describes the process for sampling soils and sending them to the laboratory to be tested for pesticide residues.
TL00316	Fact sheet	Irrigation, Soil Health	2006	Measure soil water for better farming decisions	This article is the first in a series aimed at showing how measurements of soil water availability can help farmers make more profitable decisions about crop management.
TL00319	Fact sheet	Soil Health	2006	Lift soil microbe activity to reduce disease	This fact sheet details how to manage cropping soils to stimulate a natural level of disease suppression.
TL00002	Fact sheet	Soil Health, Land use, Irrigation	2005	Beneficial bacteria beat water repellency	This information sheet is about addressing water repellent soils in the southern and western grain belt by using beneficial bacteria in them.
TL00010	Fact sheet	Soil Health, Productivity	2005	Diagnosing and ameliorating problem soils: decision tree on how to diagnose and ameliorate problem soils	This factsheet provides an overview of the simple decision tool for farmers and advisers that can be used in identifying and quantifying soil problems in agricultural soils in WA.
TL00037	Fact sheet	Soil Health, Productivity, Nutrition	2005	Soil fungi	This factsheet on soil fungi gives an overview of the different groups, incidence, impact, and management of the soil fungi.
TL00302	Fact sheet	Soil Health	2005	Soil acidity and liming	This fact sheet includes important information about soil acidity under the following headings: acidic soils in NSW, the impacts of soil acidity, causes of acidification of the soil, how soil acidity reduces crop and pasture production, reducing the impact of soil acidity on agriculture, managing soil acidity with limestone, and estimating rates of soil

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					acidification.
TL00318	Fact sheet	Soil Health	2005	Management of soil acidity in agricultural land	Soil acidity affects two-thirds of Western Australia's wheatbelt and costs the farming community in excess of $70 million annually through lost production. This fact sheet provides information on the management of soil acidity in agricultural land.
TL00321	Fact sheet	Chemical residues, Soil Health, Nutrition	2005	Nitrates in the groundwater beneath horticultural properties	This fact sheet details information on the nitrates in the groundwater beneath horticultural properties.
TL00029	Fact sheet	Soil Health, Productivity, Crop Management	2002	Optimum soil pH for crop plants	This factsheet analyses the factors that affect the actual optimum soil pH for a crop.
TL00035	Fact sheet	Soil Health, Productivity, Environmental management	2002	Soil acidity has an effect beyond the paddock Acid Soil Action Leaflet No 8	This factsheet highlights the seriousness of soil acidity and explains the off-site effects of soil acidity in relation to the water cycle. It also explains the management strategies to reduce the off-site effects of soil acidity.
TL00045	Fact sheet	Fertilizers, Soil Health, Productivity, Nutrition	2002	Why phosphorus is important	This study established the importance of phosphorus as one of the major plant nutrients in the soil.
TL00001	Fact sheet	Soil Health, Environmental management	1999	Are my soils acid? Acid Soil Action Leaflet No. 3	This publication indicates signs that soils could be acidic by determining and testing the acidity of soils.
TL00332	Fact sheet	Soil Health		Roots and bugs unearthed	This project is examining plant roots, the organisms that live on them, and whether their interactions might be used to improve crop yields.

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VG09105	Tour Report	Soil Health, Irrigation	2010	Sydney Basin Vegetable grower study tour to California July 09	This report details the outcomes of the California study tour 2009, which focused on reviewing the large scale vegetable production areas in California.
TL00034	Web page	Soil Health, Productivity	2007	Preparing soil for vegetable crops: Soil organic matter and pH	This factsheet provides an overview on preparing the soil to improve the growth of crops and reduce risk of heavy losses from diseases such as seed rots.
TL00283	Web page	Productivity, Soil Health	2004	How earthworms can help your soil	This web page provides an in-depth information on the benefits of earthworms, how to encourage earthworms, how to introduce earthworms in the soil.

10 Appendix 2. Soil health survey