Benchmarking Soil Health for Improved Crop Health, Quality and Yields in the Temperate Australian Vegetable Industries

Dr Ian Porter
Victorian Department of Primary Industries (VICDPI)

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Porter *et al*

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Benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries.
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Researchers at the Victorian Department of Primary Industries have found that a range of different soil health practices have both environmental and economic benefits to growers in benchmarking studies of over 37 sites and conduct of eight short and long term field trials. Measurements of key biological, physical and chemical properties in soil have identified crop production methods improve soil quality, whilst providing optimum yields and maximum profit. To date, field trials have demonstrated that profit gains up to $6,000/ha per crop can be obtained by use of more environmentally-friendly slow release ammonium based fertilisers and a range of organic products (eg chicken manure, biofumigants and composts). A user friendly computer-based tool ('C-Calc') has been developed to help estimate the amount of organic matter that is being returned to the soil from different rotations and organic amendments, and a series of information leaflets on use of organic matter and soil health have been developed. A soil health management plan is being produced to improve soil health and reduce environmental flows and improve the sustainability of vegetable cropping in temperate Australia.

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1 Media summary

Researchers at the Victorian Department of Primary Industries have found that a range of different soil health practices have both environmental and economic benefits to growers. By measuring biological, physical and chemical properties in soil they also have identified which methods improve soil quality, whilst providing good yields and maximum profit.

The bottom line
Field trials conducted annually over 3 seasons have demonstrated that yields can be increased by 15% and profit increased by up to $6,000/ha per crop by use of more environmentally-friendly ammonium based fertilisers which contain inhibitors to nitrification and thus produce nitrate at controlled rate over the growing season.
Field trials also showed that organic products varied widely in their ability to promote crop productivity and disease suppression. This was dependent on the nutrient value, the carbon form (labile or inert) and the ability to produce organic toxins. Chicken manures, composted green wastes and biofumigants (eg. Fumafert) provided consistent gains in crop productivity of up to 10% compared to the grower standard conventional program.
At one large commercial farm, trials also showed that a 20% reduction in irrigation resulted in a 5% yield gain for non-fumigated treatments.
A longitudinal study showed that continuous vegetable production can cause large declines in soil carbon – at one site it declined 66% over 7 years.
A user friendly computer-based tool (‘C-Calc’) has been developed to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.
A series of six information leaflets on use of organic matter and soil health has also been developed.
A soil health management plan is being produced to improve soil health and reduce environmental flows.

Good soil health is largely driven by the amount of carbon in the soil which provides both the food for soil organisms (good and bad) and helps build the good soil structure required for root growth and water storage. Agricultural practices tend to reduce soil carbon levels, and the greater the intensity of cultivation, the greater the loss in soil carbon will tend to be.

A range of tests can be used to estimate whether your soil has a soil health problem, and whether it is principally a soil physical, chemical or biological issue (eg. penetrometer resistance, nutrient and biomass measurements). These tests allow growers to compare their soils within districts. Benchmarking trials carried out by DPI Victoria comparing over 37 sites in the temperate vegetable industry showed many growers were overusing fertilisers with 70% of sites recording high or excessive levels of phosphorus and 90% of sites recording excessive levels of potassium.

The value and feasibility of a National benchmarking program for the Australian vegetable industry, similar to the soil health score card developed by Cornell University is currently being assessed. This would benchmark soil health information

on parameters found in guides (eg soil health ute guide) for each district and this will be further explored in future projects.

2 Technical summary

Pesticide withdrawals and increased consumer demand for produce with minimal chemical inputs are placing pressure on growers to adopt alternatives for managing soil-borne diseases in vegetable crops. Growers are considering better ways of managing soil health for more sustainable cropping production. Amending soils with carbon inputs, such as green manures, animal manures, composts and other carbon inputs, has the potential to both improve soil health and increase disease suppression. In the past, however, inconsistent results with carbon amendments in soil have limited their use for disease control purposes.

Over the past 3 years, the Victorian Department of Primary Industries, with financial support from Horticulture Australia Limited and the Vegetable Industry Levy, has investigated the effects of common soil management practices on soil health and crop productivity in the vegetable industry. Examining the physical, chemical and biological changes in soil after different treatments are applied has enabled them to identify cropping practices which improve soil health. In addition, the potential cost / benefit of several key organic and inorganic amendments used throughout the vegetable industry has been determined by measuring the response of crops after treatment.

The data collected in the 37 benchmarking studies indicate that nutrient inputs in Australian vegetable production are largely matched to the crops requirements with the exception of phosphorus. Phosphorus levels in vegetable growing soils were generally well in excess of crop requirements with 70% of sites having high to excess phosphorous. A subsequent trial conducted on a major commercial property showed that fertiliser input could be reduced by up to 50% without affecting yields. This pilot study has identified soil indicators that differ between soil types and management practices. These indicators and other soil parameters which have known acceptable ranges (eg 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.

A series of glasshouse and laboratory trials conducted under controlled conditions investigated the effect of amending soils with different carbon inputs against specific diseases of vegetable crops. Of the carbon amendments investigated:

- Compost and humate showed the greatest potential for suppressing (by up to 60%) damping-off of radish caused by *Rhizoctonia solani*. Adding some forms of biochar (those produced from rice hulls) increased damping-off by up to 4 fold.
- Carbon amendments that reduced soil pH, such as lignite, increased the expression of clubroot in brassicas. These amendments may require reformulation or co-application with lime in areas where clubroot is a problem. In contrast, green waste compost in laboratory trials increased soil pH and biological activity, and suppressed clubroot expression compared with other carbon amendments.
- Vetch and biochar showed potential for accelerating the degradation (up to 40% greater after 1-month) of survival structures (sclerotia) of *Sclerotinia minor* (the cause of lettuce drop) in soil.

Laboratory trials also demonstrated a relationship where adding active or ‘labile’ carbon to soil increased soil biological activity. It is thought that increasing biological activity in soil may be important in generating disease suppression through ‘antagonism’ against pathogens. Therefore, measuring soil biological activity after amending soils with carbon inputs could be one important indicator for predicting disease control in the field. However, more research is required to better understand the mechanisms (eg the biological and chemical shifts in soil) of disease suppression by carbon amendments to give growers more reliable disease control systems. This will require further research investment by industry, but ultimately the benefits will include: increased sustainability of production, more reliable disease control with reduced pesticide inputs, and increased carbon sequestration into soils.

Five short and two long term trials on commercial vegetable farms in sandy soils have demonstrated the benefits of utilising sustainable cropping practices:

- Treatments which reduce environmental nutrient flow (eg. slow release ammonium fertilisers and targeted nutrient treatments) gave yields of broccoli and profitability at least 20% greater than the standard grower practice and equivalent to the use of fumigant chemicals. This translated to increased profits of $2,000 to $6,000/ha, depending on the year and season.
- Organic treatments such as chicken manure, composted green waste and silage increased yields by an average of 5 to 15% and increased organic carbon in soil by over 100%. However, profit margins were only just starting to increase over the long term in the 3rd season of treatments.
- In some trials, water use could be reduced by 20% in soils treated with organic composts without affecting yields, although water availability was not affected.

In one long term study over 3 years there were consistent trends towards increased yield relative to standard practice for the organic amendments compost, chicken manure and silage. Metham sodium fumigation increased yield to a lesser extent. The greatest yield increases and profits occurred in the first year of the trial when higher rates of all organic amendments were used. The application of lignite reduced yield relative to the standard practice treatment.

Profit increases of up to $6000/ha occurred with the addition of organic amendments for individual crops, but there were no consistent increases in profitability over the course of the long term trial. Over the 3 years chicken manure was cost neutral and silage reduced profitability by approximately $200/ha. Compost resulted in yield increases, but the high cost of the material resulted in a relatively large decrease in profitability relative to standard practice.

In the first two years of the trial, clubroot severity at harvest was very low. In the third year of the trial when a broccoli crop was grown over summer (temperatures more conducive to disease), chicken manure and both rates of lignite increased clubroot severity relative to the standard practice treatment. Composted organic mulch had significantly greater clubroot severity than both the metham sodium and silage treatments, but this increase was not significantly different to the standard practice treatment. Soil pH was decreased by varying degrees by the different organic amendments and decreased pH and leaf boron levels were associated with increased clubroot severity. The pH effect on clubroot may be mitigated by reformulating the amendments or co-applying lime.

Increased soil levels of available plant macro nutrients, in particular potassium, nitrogen and phosphorus, were observed for organic amendments. In the field experiments in this project, 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. This supports that the increased biological activity occurring from organic amendments has increased mineralization of nutrients from organic matter thus decreasing reliance on chemical fertilizer inputs.

Soil carbon was increased by the addition of organic amendments with the greatest increases occurring for compost followed by the high lignite rate and then chicken manure then silage. The increases relative to the standard practice treatment were greatest at the start of the first year of the trial (up to 100%) when higher rates of the organic amendments were used (11-20 t/ha carbon) compared to year 3 when increases were up to 50% when lower amendment rates were used (5 t/ha of carbon). Between crops, however the organic carbon did not build to higher levels with subsequent applications of organic amendments. This finding is very important as it shows that tillage and crop management are burning off the carbon and that minimising tillage should have significant effects in these soils. This work is anticipated in future studies.

The application of Pinegro compost, chicken manure and lignite all significantly increased the water holding capacity (WHC) of the soil compared to standard grower practice and fumigation with metham sodium. Soils treated with these organic soil amendments had a higher WHC at both 10 and 40 kPa, however, readily available water capacity (RAWC), the water stored in the soil that easily extracted by plants, is calculated to be the difference in WHC between these two pressures (10 and 40 kPa). Because the application of these organic amendments increased WHC at both of the pressures, there is no additional water available to the plants. In other words, although the application of these organic soil amendments increased the amount of water held by the soil, the additional water was held very tightly and therefore would not be available to the crop.

Findings from these two experiments are contrary to the common belief, that the application of organic soil amendments, and particularly compost, significantly increases both soil water holding capacity and plant or readily available water content. This work therefore needs to be expanded to include a wider range of organic soil amendments, application rates and soil types to determine the situations where the current findings are true.

Finally, a longitudinal study conducted on 4 paddocks within the one grower's property showed the effect of vegetable farming from pasture to 1, 3 and 7 years of vegetable production on the physical, chemical and biological characteristics of the soil. At the sites all paddocks were managed by the same farmer who used comparatively high levels of organic matter inputs compared to the local vegetable industry. This included retaining crop residues, growing green manure crops, and applying chicken manure.

Despite the high level of organic matter returned, it was found that the paddocks that had been in vegetable production longer had lower soil organic carbon levels. On average this was equivalent to 0.2% less total organic carbon (TOC) in the 0-30 cm soil layer per year. The long-term, lightly grazed, pasture in the zero year paddock demonstrates that high levels of total organic carbon can be established even in sandy soils under a suitable farming system. Phosphorous and copper were found to be 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.

Further work is required to optimise the application of organic amendments for vegetable production and ensure their application is made at the right time of year when the crop and the soil can maximise the benefits of application. Results suggest that the organic amendments have improved soil health (increased biological activity, increased organic matter and lower fertilizer requirements) however three of the four amendments promoted clubroot disease due to a fall in pH and lower boron content. Future trials need to find ways to maintain a balance between yield increase and disease to ensure sustainable practices can be maintained throughout the temperate cropping industries in Australia.

The project had a major component devoted to extension with over 30 grower seminars and workshops being conducted, 14 national conference presentations, 4 info leaflets prepared, 3 radio interviews, 3 articles in Vegetables Australia including a Vegenote and ‘Soil health management chart’ and a handout on ‘Improving Soil Health distributed to over 300 growers at the workshops during the project.

3 Introduction

Pesticide withdrawals and increased consumer demand for produce with minimal synthetic inputs are placing pressure on growers to adopt alternatives for managing soils and soil-borne pests (e.g. diseases, weeds) in vegetable crops. In response to a scoping study on soil health (VG06090), HAL and the vegetable industry requested that this project identify the cost/benefits that could be gained by investment in soil health research. In particular, what benefits would 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.

In response, benchmarking studies commenced in the scoping study project VG06090, were continued (Chapter 4). These included taking soil samples at 37 sites in southern Australia to get further baseline data of the effect of sustainable practices (conventional verses more organic) on soil quality parameters indicating better soil health. These studies continue the development of a national database of key threshold values for key soil health parameters in the national vegetable industry.

In addition, six short term and two long term field trials were conducted at commercial vegetable farms in Victoria and Tasmania to determine the impact of common farm practices used throughout the National vegetable industry on soil health, crop productivity and grower profit (Chapter 6). These trials also assessed which soil health indicators best measured the physical, chemical and biological changes that occur with the different practices. The short term Victorian trials examined the effects of fumigants, fungicides, fertilizers and composts on crop yield and soil characteristics. A short term Tasmanian trial 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 (Chapter 5).

Two long term trials were carried out to evaluate the effects of more sustainable cropping practices using different organic amendments and rotation crops on crop productivity and soil health (Chapter 6). The trials were conducted at separate locations in Victoria, at Boneo on the Mornington Peninsula and Devon Meadows approximately 50 km South East of Melbourne. Organic amendment treatments were repeatedly applied to the same plots over a three year period to determine which amendment provided the best response in yield, disease suppression and building organic carbon. Changes in soil carbon, organic matter, biological activity, crop yield and disease were monitored over the three year period. Over 25 soil physical, biological and chemical parameters were also recorded (See chapters and Appendices).

Good soil health is largely driven by the amount of carbon in the soil (Janvier *et al.* 2007), which provides both the food for soil organisms (good and bad) and helps build the good soil structure required for root growth and water storage. Cropping practices within the vegetable industry, especially tillage tend to reduce soil carbon levels, and the greater the intensity of cultivation, the greater the loss. Within raised bed vegetable production systems in Australia, soils are typically cultivated many times prior to planting. As a consequence, soil organic matter levels are typically low; often around 1-2%. In an effort to build soil organic matter and soil health, vegetable growers may incorporate a green manure crops, composts, animal manures or other organic inputs into soils. Chapter 7 evaluated the effect of these amendments on soil carbon, soil water and fertility on yield, whilst chapter 8 evaluated the impact of the practices on a number of key soil health characteristics, (including total organic carbon, salinity, nutrient levels, water infiltration and bulk density) over a one, three and seven year period of vegetable production.

4 Benchmarking - Soil health indicators for temperate vegetable production in Australia

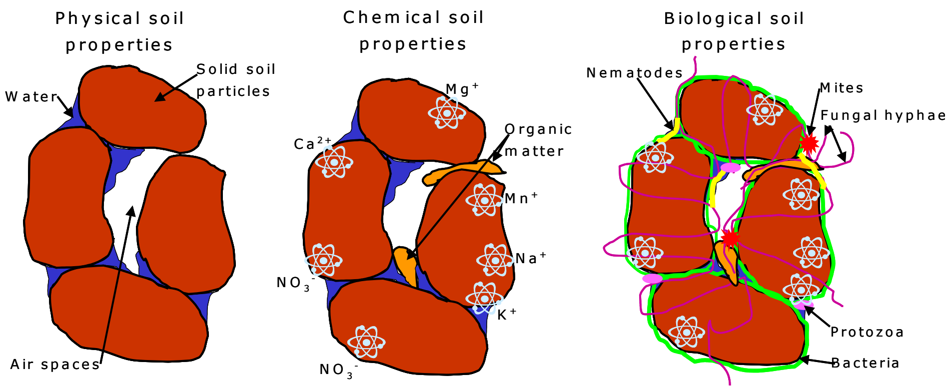
Demonstration of the benefits of benchmarking at a grower meeting in NW Tasmania.

Bob Schindelbeck from Cornell University demonstrates the importance of the rainfall simulator on soil aggregate stability.

4.1 Introduction

Soil is increasingly being recognised as an important non-renewable farm asset that needs to be managed well to maintain productivity and profitability. Accurate monitoring of soil health can enable farmers to measure the sustainability of farming practices. The resulting benefit is that management practices can be designed and used to enable growers to improve the health of soils used for vegetable production. This should result in long-term gains in resource use and better crop productivity. In most instances this is expected to result in reduced inputs of water and fertilisers, and reduction in damage caused by pests and pathogens, leading to improved yield, quality and, ultimately increases in farm income.

Soil health indicators are physical, chemical and biological tests that can be applied to soil to measure a parameter of soil quality. They may be tests that growers regularly carry out, such as pH and nutrient analyses, or may be additional tests that require the expertise of specific laboratories, such as nematode community analysis (Table 4.1).



Source: Tony Pattison, QDPIF

Figure 4.1 Physical, chemical and biological properties of soil.

As there was no prior information to establish baseline soil health data for vegetable sites in temperate Australia this study initially evaluated sites at key growers' properties to gather baseline data on physical, chemical and biological values expected within the region. This enabled a preliminary set of tables to be formed which set thresholds for the soil types within a region and thus show differences between regions. It also compliments similar studies conducted in the sub-tropical vegetable industry in Australia (Pattison 2009). These two studies are the first steps to establishing a national database of information which can be used in the future to improve grower practices to manage soil health. It will compliment the AusVeg EnviroVeg program and the related publications – The Soil Health Ute Guide and the Soil Health Websites which contain a detailed list of relevant publications and other information: www.soilquality.org, http://healthysoils.gov.au/ http://knowledge-exchange.ausveg.com.au, http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome.

One aim of this project was to evaluate a range of indicator tests for measuring soil health and determine which could be used to improve farm management practices on the health of vegetable cropping soil.

To determine which indicators are most relevant to temperate vegetable soils in Australia, more than 30 tests have been trialled over three years on a range of vegetable growing properties. Sites were selected on the basis of conventional versus higher organic matter inputs and fumigated versus non-fumigated in order to identify which soil health indicator tests were best able to identify the expected differences between sites according to farming practice.

Table 4.1 A list of the soil health indicator tests used and evaluated in this project

Soil physical tests	
Penetrometer resistance (at limited sites)	A penetrometer is pushed into the soil and readings of increased resistance may indicate compaction layers as the probe moves through the soil profile. Useful to estimate resistance to root growth in soil and possible remediation treatments (deep ripping, organic matter incorporation) to improve soil structure.
Aggregate stability (at limited sites)	Indicator of soil structure. A well-structured soil has stable aggregates that are not easily dispersed in water. Can be used to guide improvements in traffic management and tillage.
Water infiltration (at limited sites)	Soil water infiltration can be measured by determining the rate at which a set volume of water infiltrates into soil. The rate is strongly correlated to management practices. A well-structured soil has enough pores to promote aeration, water infiltration and allow roots to easily penetrate through the soil.
Soil chemical tests	
Soil pH	pH is an indicator of acidity or alkalinity of soil and the thresholds for crop growth. pH also influencess nutrient form and availability.
Nutrient analyses	A large number of macro and micro nutrients were measured, eg. (see below). Insufficient nutrients reduce plant growth and vigour, but an oversupply of nutrients can be toxic to plant growth and pollute waterways through leaching.
	Macro nutrients: - N, P, K, Ca
	Micronutrients: - S, Cu, Mn, Mg, Zn, Fe, Na
Labile carbon	An indicator of the fraction of soil organic matter easily degradable and readily available as food for soil microbes. Positively correlated with % organic matter and aggregate stability. Particularly useful to monitor practice changes for building up soil organic matter.
Cation exchange capacity (CEC)	The CEC describes the ability of the soil to retain nutrients in the vicinity of the root zone, ensuring they are available for plant use.

Table 4.1 (continued)

Soil biological tests	Soil organisms decompose plant residues, recycle nutrients, provide the 'glue' that holds soil aggregates together, and can reduce disease problems by out-competing soil-borne pathogens.
Biological activity (FDA hydrolysis and CO_2 respiration)	These are indirect measures of total soil microbial biomass.
Fungi:bacteria ratio	Gives a general indication of soil health - a higher ratio may indicate a more stable undisturbed system which most likely has higher resilience and greater biological suppression to disease.
Nematode community structure	Certain groups of microscopic worms (nematodes) feed on bacteria, fungi and other nematodes. Measurement of the relative proportions of these different nematode groups gives an indirect measure of overall soil microbial community structure, the fungal:bacterial ratio and soil resilience.

Soil health programs around the world, such as the Cornell University Soil Health Program (Gugino et al 2007), use similar indicator sets to develop programs that enable farmers to score their soil health and keep track of improvements in management practices that work for their farm. The project team evaluated whether such a program would be feasible and of use to Australian vegetable farmers using data from the current project (temperate vegetable systems) and also data from sub-tropical vegetable production.

4.2 Methods

4.2.1 Benchmarking sites

Sites were located in four major vegetable growing regions within temperate Australia. The sites had a range of soil types ranging from sands to clays (Table 4.2).

Table 4.2 Field sites used for soil benchmarking study.

Region	Site	Soil type	Crop
Bairnsdale Vic	CX	Silty Loam	Fallow
SE Melbourne	TS	Sandy	Endive
Yanco NSW	Yanco1	Sandy loam	Chickpea
Valla NSW	Yanco2	Loamy clay	cultivated
Bairnsdale Vic	Wg	Loam	Dry beans
Tasmania	H	Loamy clay	Lettuce
Boneo Vic	RL	Sandy	Broccoli
SE Melbourne	PS	Sandy	Endive

4.2.2 Sample collection

At each site, samples were collected from the top 15 cm layer of soil by pooling 10 to 20 cores (using a trowel). The pooled samples were replicated 3 to 6 times depending on the site. Samples were sent to DPI, Knoxfield for processing where they were stored at 4°C until assessment.

4.2.3 Soil chemical properties

Sub samples were sent to the Department of Primary Industries, Werribee, Victoria for chemical analysis (Table 4.3) according to their standard methods.

Table 4.3 Soil chemical and physical parameters measured at the benchmarking vegetable growing sites.

Organic resources	Total Carbon/Nitrogen (Leco)	Carbon Nitrogen Organic matter
pH and EC	pH and Conductivity	EC pH($CaCl_2$) pH(water)
Exchangeable cations	Ammonium acetate cations (with prewash)	Calcium Calcium as % Magnesium Magnesium as % Ca:Mg Potassium Potassium as % Sodium Sodium as % Sum of four cations Total soluble salts
Plant available nutrients (soil fertility)	Available Nitrogen Available Phosphorus Available Potassium Available Sulfur	Ammonium-N Nitrate-N P (Olsen) Potassium Sulfur
Trace elements	DTPA extractable trace elements	Copper Iron Manganese Zinc

4.2.4 Soil biological properties (nematodes)

Ratios of nematode populations

Nematodes were measured by either Biological Crop Protection, Qld or Agri Science Queensland, Indooroopilly, Department of Employment, Economic Development and Innovation according to the methods of Pattison (2009). These laboratories provided the percentage of pathogenic and saprophytic nematodes and categorised them into different feeding groups (bacterial feeders, fungal feeders, omnivores and predatory nematodes). Diversity was calculated using the Shannon Wiener index (H') (Yeates and Bongers 1999). The B/F ratio was also calculated (B/(B+F) where B is the proportion of bacteriovores and F is the proportion of fungivores).

The basal structure and enrichment conditions of the soil foodweb and the decomposition channel of nutrients were also determined (Ferris et al 2001). These indices were used to provide an estimation of the effect of past crop management treatments at the benchmarked sites on nematode community composition. The Enrichment index (EI) is a measure of the resources available in the soil food web and the response of primary decomposers to those resources. The Structure index (SI) is a measure of the number of trophic layers in the soil food web. The Channel index indicates the decomposition channel of nutrients with low and high values suggesting dominant bacterial decomposition and fungal-dominated decomposer nematode communities.

4.2.5 Other biological activity measurements

FDA activity
Fluorescein diacetate (FDA) hydrolysis is a method for estimating total soil microbial activity and was determined using the protocol of Schnurer and Rosewall (1982). Each analysis was performed on 5 g of air dried soil.

Soil respiration
Soils were air dried at 40^{o}C for 48 hours. Soil (30 g) was lightly packed (1 g/cm/) in incubation containers (40 mm PVC tube, 3 cm high, mesh bottom, aperture 0.06mm). Samples were wetted up to 55% water holding capacity (± 5%) by placing in 'wet up' baths of distilled water. Actual water content was determined gravimetrically. Wet up samples were then placed in an incubation chamber (1 litre air tight jar). A water reservoir (30 ml of distilled water) was placed in the incubation chamber to maintain humidity. Chambers were incubated in a controlled temperature room at 25^{o}C in darkness. CO_2 measurements were taken at 4 and 14 days using a Servomex 1450 CO_2 analyser.

Labile carbon
The labile carbon content of soil was determined on 3 g samples of air dried soil (40 ^{o}C for 48 hours), sieved to 1mm, according to the potassium permanganate method of Blair et al (1995).

4.2.6 Statistical analysis

Where possible, paired samples were taken within the sites to determine the effect of key crop management factors on soil health tests. The key criteria were :
- Crop stage (at transplating, at maturity and at harvest)
- Production method: conventional, compost amended and organic production
- Fumigation versus non fumigation.

Prior to analysis data were transformed as required to homogenise variance (Appendix 4.2).

The use of regression analysis in selecting soil measures for discriminant functions
Regression models are generally used to test associations among variables. In this study they were used to select those soil parameters which differed across the categories of *Management*, *Soil Type* or *Fumigation*. Combinations of these selected parameters were then used to discriminate the categories of *Management practice*, *Soil type* and *Fumigation.*

Please note: A soil parameter can be used to discriminate a category of management practice only if it is associated with that category. Regression analysis tests such associations.

Multivariate models
The effects of *Management practice, Soil type* and *Fumigation* all influence soil properties. A model examining the effects of one of these variables (e.g. *Management*) on soil properties should adjust for the impact of the other variables that could also affect soil properties (*Fumigation*, *Soil Type*).

Ordinary least squares (OLS) regression models
(i) "Fumigated" samples were only collected from conventionally managed, sandy soils. Therefore, a subset of the data was used to model differences in soil properties between "fumigated" and "not recently fumigated" fumigation categories in sandy, conventionally managed soils. The following OLS model was fitted:

$$\text{Soil Property} = \beta_0 + \beta_1(\textit{farm}) + \beta_2(\textit{fumigation practice})$$

(ii) Full OLS regression models, which included all categorical variables as regressors, were also fitted:

$$\text{Soil Property} = \beta_0 + \beta_1(\textit{farm}) + \beta_1(\textit{soil type}) + \beta_3(\textit{management practice}) + \beta_4(\textit{fumigation practice})$$

These models were used to estimate differences in the soil properties

- among *Management* practice categories: non-production(NP), compost enriched (CT), conventional (cl) and organic (O), after adjusting differences among farms, soil types and soil fumigation. Because of data limitations, interaction effects could not be tested.
- Between *Fumigation* categories of "Never" fumigated and "Not recently" fumigated.

Linear discriminant analysis
In linear discriminant analysis multiple soil indicators were used to discriminate among the following soil groups:

i. Soil type (clay [C]; loam [L]; sand [S])
ii. Management practice (non-production [NP]; compost-enriched [CT]; conventional [cl]; organic [O])
iii. Fumigation practice (bio-fumigation [B]; fumigation [F]; never [V]; not recently fumigated [N]

Two classification systems were used to discriminate among soil groups:

i. Resubstitution classification
An overly optimistic assessment is given about the model's ability to assign group membership to observations outside the study sample, when observations are used to create a discriminant model, and then that model is used to assign group membership to the same observations.

ii. Leave-one-out classification

A leave-one-out classification provides a more realistic assessment for future prediction (Stata 11 manual). This classification is obtained by removing each observation, one at a time, then creating a discriminant model from the remaining observations. The observation, which was left out, is then classified using the model.

Predicted probabilities were used to select soil indices, which were likely to discriminate among soil groups. This was a more effective method than using principle component (PC) analysis of soil indicators in order to select the soil indices used for discriminant analysis.

4.3 Results

The mean, standard error (SE), minimum and maximum values for the soil parameters studied are presented in Table 4.4.

Table 4.4 Soil indicator values for the benchmarking vegetable growing sites

Indicator	Unit	Mean	SE*	Min	Max
Biological					
Bacterial feeders (B)	%	67.7	3.6	8.2	90.7
Fungal feeders (F)	%	23.3	3.8	0.7	88.1
Omnivores	%	8.0	1.3	0	34.9
Predators	%	1.2	0.4	0	10.7
Enrichment (EI)	%	78.9	2.7	37.4	96.8
Structure (SI)	%	49.7	3.9	4.5	86.6
Channel (CI)	%	12.8	2.7	0.9	63.0
B/(B+F)		0.8	0.03	0.3	1.0
Free living nematodes (FLN)	%	98.4	0.7	82.1	100
Respiration 4 days	µg/CO_2 /g soil	323	27.9	90	848
Respiration 14 days	µg/CO_2 /g soil	674	54	170	1526
FDA	mg F/kg soil/hr	1.14	0.12	0.14	3.66
Chemical					
pH (water)		6.7	0.1	5.2	8.1
pH ($CaCl_2$)		6.3	0.1	4.8	7.7
EC	dSm^{-1}	0.20	0.01	0.07	0.48
TSS	%	0.07	0.005	0.02	0.17
Total Carbon (C)	%	2.1	0.2	0.6	6.2
Oxidisable organic C	%	2.1	0.2	0.7	5.7
Labile C	%	648	38	279	1043
Total Nitrogen	%	0.15	0.01	0.04	0.32
Ammonium N	mg/kg	2.3	0.5	0.4	18
Nitrate N	mg/kg	21.1	2.4	6.3	64.0
P (Olsen)	mg/kg	92.4	7.1	13.0	160
K (available)	mg/kg	229	26	56	770
S (available)	mg/kg				
Ca	meq/100 g	5.9	0.3	1.8	13.0
Mg	meq/100 g	1.3	0.1	0.3	3.1
K	meq/100 g	0.4	0.1	0.1	1.8
Na	meq/100 g	0.09	0.01	0.00	0.31
Ca:Mg		5.6	0.4	1.8	11.0
Ca as %	%	77.2	1.5	53.7	89.7
Mg as %	%	16.6	1.1	8.0	33.3
K as %	%	5.0	0.7	0.8	23.0
Na as %	%	1.1	0.2	0.0	4.0
Sum of 4 (Ca,Mg,K,Na)	meq/100 g	7.7	0.4	2.4	16.0
Cu	mg/kg	2.3	0.2	0.2	4.5
Fe	mg/kg	83.1	11.7	13.0	270
Mn	mg/kg	5.8	0.9	2.0	24
Zn	mg/kg	7.1	1.0	0.6	40

* Standard error

4.3.1 Soil properties and nutrient benchmarking

All soil properties were categorised according to Hazelton and Murphy (2007) unless otherwise stated. More than 75% of soil pH values were in the slightly acidic/slightly alkaline category (pH 6-8). Approximately equal proportions were moderately alkaline and moderately acidic. Three soils were classified as strongly acid but one was from a non-production site and the other two were from the same farm.

Sodium and chloride levels were low at all sites. Only one sample was classified as moderately saline on the basis of EC and this was a non-production soil. The majority of soils were classified as non-saline (63%) while the remaining 35% were classified as slightly saline.

Total carbon was relatively high with only 18% of soils being classified as low carbon, the majority of sites had moderate to high soil carbon. Further improvements to soil carbon levels, however, may give growers additional benefits of improved disease suppression.

Available phosphorous (Olsen) was generally high with an average value of 92 mg/kg across all sites. Seventy percent of sites had more than 50 mg/kg available phosphorus, a level sufficient for production of most vegetables (Prasad et al 1988). Two out of the three lowest available phosphorus values were from non-production soils (available P < 20 mg/kg). The percentage of vegetable production sites with available phosphorous in excess of requirements increases to 75% (when the two non-production sites are excluded from the data set). This phosphorus accumulation in vegetable growing soils relative to non-production soils is similar to that observed by Chan et al (2007). It suggests that for the majority of vegetable farms, inputs of phosphorus fertilizer may be greatly reduced without affecting yields.

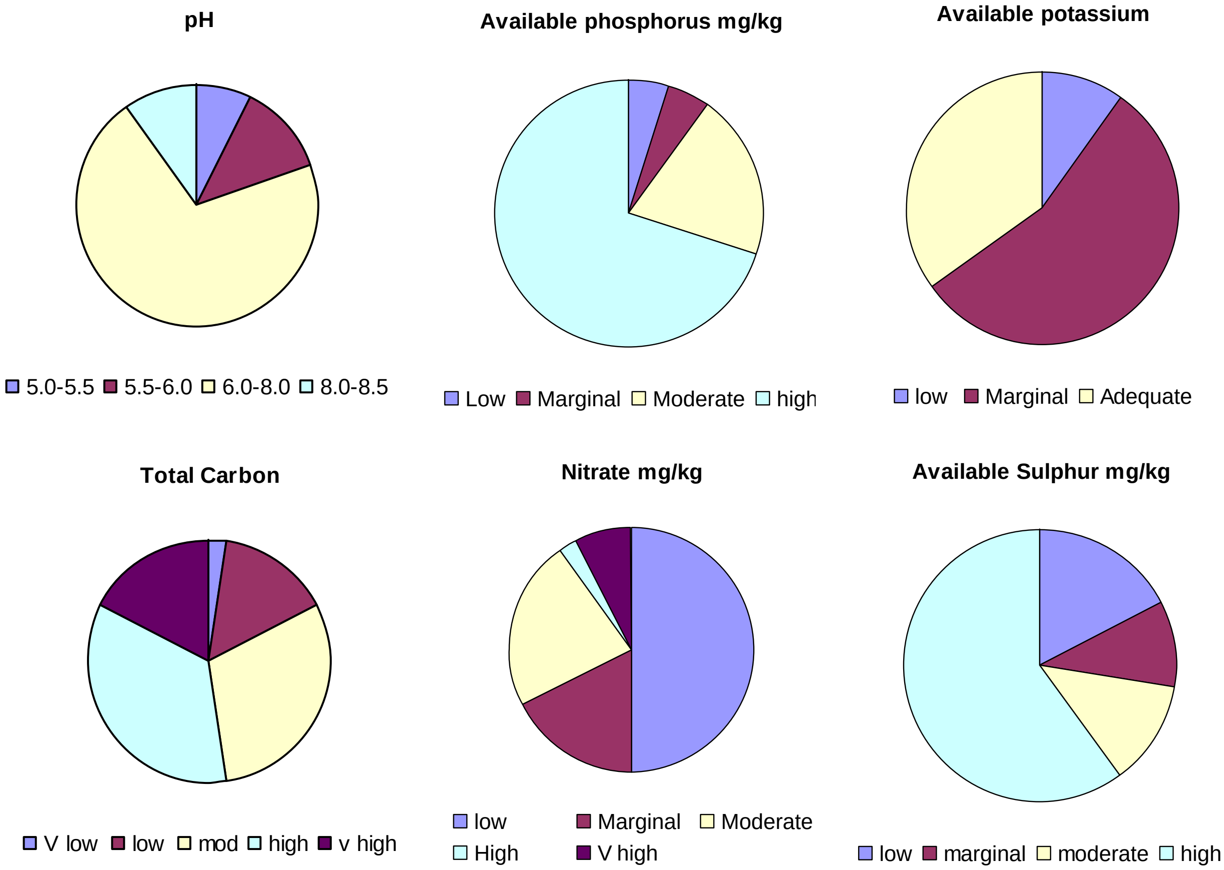


Figure 4.2 Soil properties across the benchmarking vegetable growing sites

Available potassium was low at 10% of sites while 55% were marginal and 35% had adequate soil concentrations. When only transplanting soil samples were compared, 64% had adequate available potassium.

Nitrate was the dominant form of available nitrogen at all vegetable growing sites although the two non-production soils had equal or greater amounts of ammonium nitrogen. Nitrate was low to marginal in 67.5% of soil samples. Two of the vegetable production soils with low nitrate had relatively high levels of ammonium nitrogen (>2.9 mg/kg). However, when only samples collected at transplanting were compared, all of the samples with low nitrate came from the same farm. Most of the sites had adequate available sulphur but 18% had low levels.

4.3.2 Nematode faunal analysis

An analysis of nematode indices in bidimensional space using the soil health quadrats of Ferris et al (2001) indicated that vegetable farms are represented by low-high disturbance, nitrogen-enrichment, and a low C:N ratio (quadrats A and B) (Figure 4.3). Approximately half of the sites fell into quadrat A (defined by high disturbance, nitrogen enrichment, low C:N ratio and a basic, disturbed food web) and all of these were transplanting samples. The majority of the remainder fell into quadrat B (defined by low-moderate disturbance, nitrogen enrichment, a low C:N ratio and a maturing food web) and most of these samples were collected at harvest. Only two sites (from one farm) were represented in quadrat C (undisturbed, moderate N-enrichment, moderate-high C:N ratio).

The only site to fall into quadrat D (defined by stressed, nutrient depleted soil with a high C:N ratio and a degraded food web) was one of the non-cropped sites.

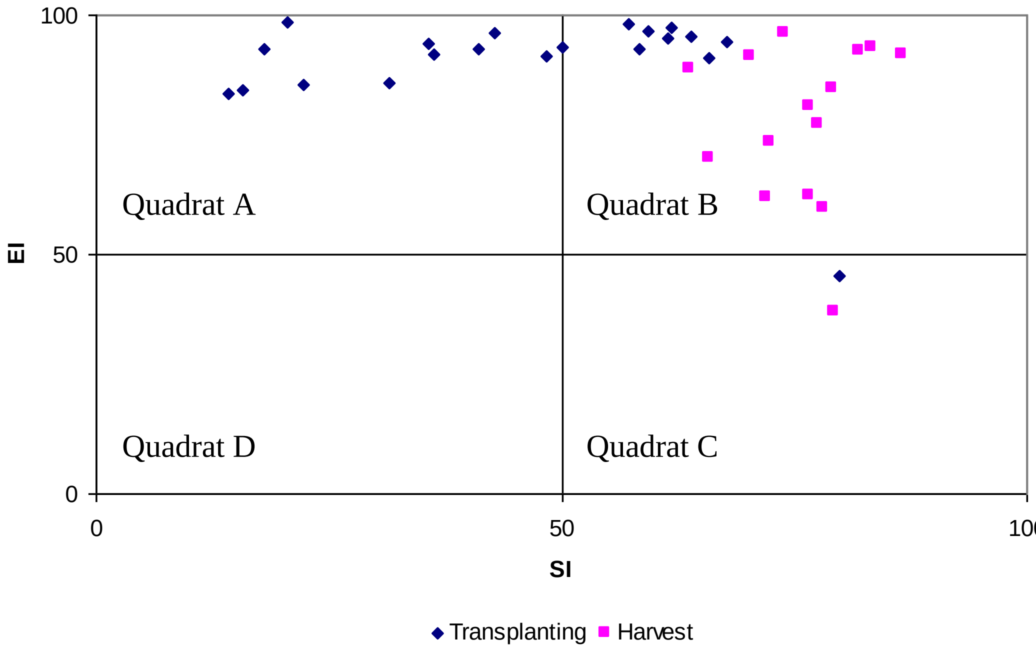


Figure 4.3 Nematode bidimensional space at transplanting and harvest for the benchmarking field sites

4.3.3 Selection of soil properties as indicators of soil health

A number of the soil properties showed a high degree of correlation with each other. Most of these measured similar soil factors and therefore the high degree of correlation was expected. However, there was also a strong correlation between soil biological activity (FDA) and the proportion of bacterial feeding nematodes. This suggests that bacteria explain most of the variability in biological activity in vegetable soils. Properties with high correlations (R>0.8) were compressed into principal components which reduced the number of soil variables from 41 to 24 (Table 4.5).

Table 4.5 Grouping highly correlated measures of soil properties into principal components

group	Grouped variables	Correlations	PC1 variance loading	New variable
1	total carbon total organic matter total nitrogen oxidizable organic carbon oxidizable organic matter	R>|0.97|	98.87%	C_N_PC
2	available K K K as percent	R>|0.88|	92.79%	K_PC
3	Na Na as percent	R>|0.89|	94.6%	Na_PC
4	EC total soluble salts available S	R>|0.86|	94.06%	S_salt_PC
5	Ca sum of 4	R>|0.91|	91.15%	Ca_so4_PC
6	Ca as percent CaMg_ratio Mg as percent	R>|0.92|	95.59%	MgCa_cent_PC
7	CO_2 14 days CO_2 4 days	R>|0.94|	96.79%	CO_2_PC
8	FDA bacterial feeding nematodes	R>|0.94|	97.1%	FDA_bf_PC
9	pH water pH $CaCl_2$	R>|0.98|	97.75%	pH_PC
10	channel_index B/(B+F)	R>|0.83|	91.59%	BBF_ci_PC

4.3.4 Soil carbon management (compost amendments and organic systems)

Non-production soils differed from conventional vegetable production soils in 6 parameters (5% significance) (Table 4.6). The non-production soils had lower nitrate, available phosphorus, copper and pH relative to the vegetable production soils. Non-production soils had higher total carbon, total nitrogen and respiration than production soils. Fungal feeding nematodes were on the borderline of being significantly different and were more abundant for the non-production soil than the conventional vegetable production system (Table 4.7). There was a corresponding increase in bacterial feeding nematodes for conventional production relative to non-production. Compost amended and organic production had intermediate values for fungal and bacterial feeding nematodes and can be considered to be less disturbed systems than conventional production (synthetic fertilizer only). Similar changes in the relative abundance of nematode feeding groups has been shown for sites with differing degrees of disturbance (Figure 4.4).

Table 4.6 Significance of the impact of management practice on soil properties: comparisons with conventional practice. The data was obtained from the multivariate regression models.

Transformed dependent variables	comparison of management categories with "conventional" practice (N=18)		
	non-production N=2 [p-value]	+ compost N=6 [p-value]	Organic N=2 [p-value]
omni_nematodes	0.205	0.531	0.382
structure-index	0.902	0.748	0.996
bbf_ci_PC	0.302	0.422	0.176
K_PC	0.185	0.264	0.992
S_salt_PC	0.485	0.226	0.579
Mn	0.856	0.214	0.661
CaMg_cent_PC	0.728	0.726	0.318
enrichement-index	0.495	0.232	0.991
Na_PC	0.182	0.182	0.123
labileC	0.890	0.128	0.117
ff_nematodes	0.060	0.277	0.788
NO_3	0.014	0.962	0.564
CO_2_PC	0.015	0.032	0.448
C_N_PC	0.029	0.001	0.054
pH_PC	0.045	0.381	0.039
OlsenP	<0.001	0.111	0.035
Cu	0.001	0.824	0.073
NH_4	0.146	0.062	0.049
FDA_bf_PC	0.837	0.227	0.001
Mg	0.607	0.361	0.008
Fe	0.454	0.401	0.004
Ca_SO4_PC	0.326	0.132	0.001
Zn	0.270	0.075	0.062

•p-values of borderline significance: these may be regarded as less reliable for "+compost" category because of the larger sample size

There were only three variables that separated soils with compost additions from conventional production soils, namely soil respiration and total carbon and nitrogen, all of which were higher for the compost amended soils (Table 4.7).

Table 4.7 Mean values for parameters that were significantly different between the conventional production system and the other types of management.

Variable	Conventional production	Compost amended production	Organic production	Non-production
Fungal feeders*	18.39	30.88	35.46	53.55
Bacterial feeders	72.0	59.9	60.2	40.3
NO_3	20.86	21.73	36.0	7.383
CO_2 4 d	273.8	443.3	356.3	589.9
CO_2 14 d	553.5	910.7	771.6	1487.0
Total Carbon	1.90	2.35	2.67	3.68
Total Organic matter	3.50	4.34	4.93	6.83
Total Nitrogen	0.136	0.163	0.212	0.252
pH water	6.67	7.08	6.63	5.90
pH $CaCl_2$	6.26	6.53	6.2	5.45
Phosphorus (Olsen)	101.7	91.33	37.17	17.17
Cu	2.59	1.54	1.20	0.97
NH_4	1.425	2.82	3.25	12.15
FDA	1.16	0.84	0.57	2.47
Mg	1.10	1.77	2.87	1.58
Fe	73.32	12.30	55.33	111.50
Ca	5.79	5.61	10.20	4.40
Sum of 4 cations	7.26	8.02	14.0	6.42
Zn	6.72	5.41	5.12	21.07

* parameters were on the borderline of significance at 5%

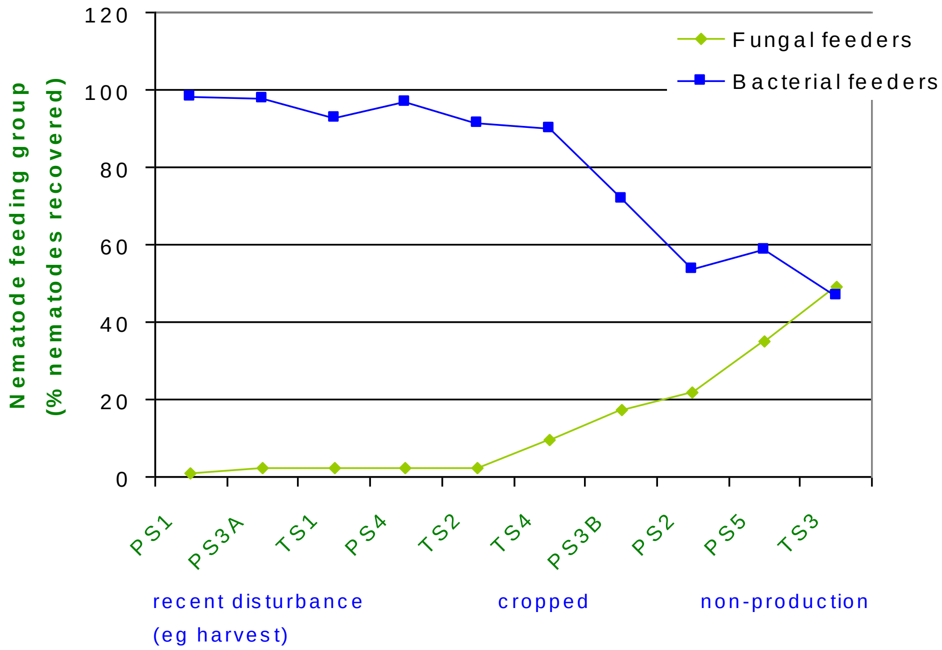


Figure 4.4 Relative abundance of nematode feeding groups relative to soil disturbance (reproduced from Porter et al 2007). Resilience improves from left to right of figure

4.3.5 Fumigation practice

Two sets of comparisons were made among categories of *Fumigation* practice. The first comparison, "fumigated" vs. "not recently fumigated" ("F" vs. "No") was performed using a subset of the data. Samples from fumigated soils ("F") were collected from only one soil type (sandy) and one management practice (conventional).

This subset of data enabled a comparison of "Fumigated" vs. "Not fumigated" categories. The results of an OLS (Ordinary Least Squares) regression model are given in Table 4.8. The results suggest that for conventionally managed, sandy soils:

- there are significant differences in soil properties among farms,
- there are no detectable differences in soil properties between fumigated and not recently fumigated categories

Controlled studies (Porter et al., 2005) have shown that soil fumigation can dramatically affect soil biology (e.g. reduce populations of soil fungi by more than 99%) and chemistry (e.g. increase mineralisation of nitrogen and concentrations of soil ammonium by up to 5-fold). These effects may persist for periods up to a year and perhaps longer using very effective fumigants, such as methyl bromide (Porter et al., 1999). Therefore, the most accurate interpretation of results from the current study is that the effects of fumigation with metham sodium may persist in soils for shorter periods. Therefore, differences in soil parameters between 'fumigated' and 'not recently fumigated' soils are difficult to detect. In the future, this hypothesis could be further tested if greater numbers of samples from soils that have 'never been fumigated' are incorporated into the current database.

Table 4.8 Model selection for "fumigation" effects, adjusted for soil type in conventionally managed soils.

Transformed measures of soil variables	Farms (p-value)	"Fumigation" vs. "not recently fumigated" (p-value)	Adjusted R^2
ff_nematodes	0.547	0.629	-0.09*
omni_nematodes	0.237	0.345	0.31
EI	0.073	0.183	0.29
SI	0.391	0.956	-0.04
NH_4	0.526	0.454	-0.06
NO_3	0.011	0.939	0.57
OlsenP	0.001	0.584	0.01
Cu	<0.001	0.985	0.94
CO_2_PC	0.253	0.963	0.03
Mn	0.393	0.919	-0.05
Na_PC	0.872	0.894	0.05
FDA_bf_PC	<0.001	0.736	0.94
bbf_ci_PC	0.982	0.804	0.02
labileC	<0.001	0.843	0.79
C_N_PC	<0.001	0.972	0.95
pH_PC	<0.001	0.734	0.81
Mg	<0.001	0.640	0.17
Fe	<0.001	0.856	0.10
Zn	<0.001	0.839	0.95
K_PC	0.003	0.853	0.54
S_salt_PC	<0.001	0.337	0.64
Ca_so4_PC	<0.001	0.956	0.82
CaMg_cent_PC	0.005	0.785	0.50

***** In regression models, R^2 is called "the coefficient of determination". It provides information about the goodness of fit of a model. In regression it estimates how well the regression line approximates real data. Adjusted R^2 is R^2 that had been modified to account for the number of independent variables in the model. It is always less than or equal to R^2. The adjusted R^2 can be negative if the number of independent variables equal the number of observations:

$$\text{Adjusted } R^2 = \frac{error..\text{var}iance}{total..\text{var}iance} = \frac{SS_e / (n-p-1)}{SS_t / (n-1)}$$

where n is the number of observations and p is the number of independent variables.

4.3.6 Discriminant analysis

Soil Type

Four soil indicators were required to distinguish among categories of *Soil type* (Figure 4.5 A). These indicators were:

Zn_L: log-transformed ($ln_e Zn$) measure of Zinc
Fe_L : log-transformed ($ln_e Fe$) measure of iron
PC_pH: principle component derivative of two pH measures (in water and in $CaCl_2$ solution)
PC_bbf_ci : principle component derivative of transformed B/(B+F) ratio and CI measures

The Leave-one-out classification (Figure 4.5 B) failed to correctly assign one out of 37 observations, despite using two additional indicators (6 in total):

Cu_isr : inverse square root transformation of Cu measure
PC_CO2: principle component derivative of log-transformed (ln_e) measure of CO_2.

- Using additional indicators did not improve discrimination in the leave-one-out classification.
- Using the first nine PCs of all transformed soil indicators (>90% variance explained) did not rectify the misclassification of the soil sample.

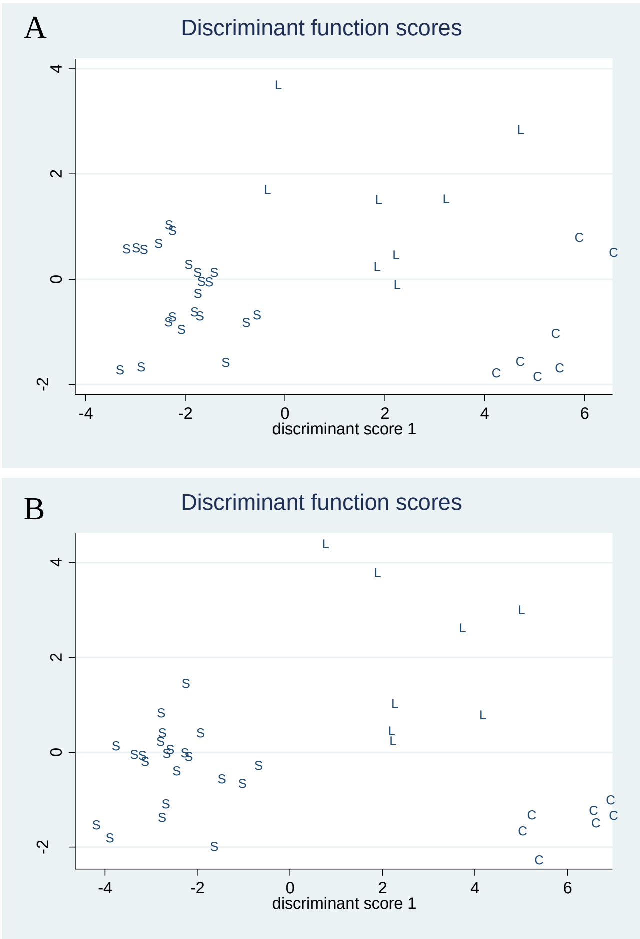


Figure 4.5 Discriminant function scores used to segregate Soil type categories (clay [C]; loam [L]; sand [S]) using A) 4 indicators (Resubstitution classification) and B) 6 indicators (leave-one-out classification)

Fumigation

Eight soil indicators were required to distinguish among categories of *Fumigation* (Figure 4.6). These indicators were :

e_index_i	enrichment index
PC_bbf_ci	principle component derivative of transformed B/(B+F) ratio and c-index measures
PC_S_salt	principle component derivative of transformed available S and total salt (EC &%TSS) measures
s_index_sqrt	square root transformation of S-index
PC_Na	principle component derivative of transformed sodium measures
Fe_L :	log-transformed (ln_eFe) measure of iron
Mg_L	log-transformed (ln_e) measure of magnesium
PC_FDA_bf	principle component derivative of transformed FDA and %BF measures

There was misclassification in 4 out of 37 observations: two N (not recently fumigated) sites were misclassified as F (fumigated) sites. In addition two F sites were misclassified as N. Previously discussed regression analysis failed to detect differences between these two categories.

The Leave-one-out classification failed to correctly assign 17 out of 37 observations. This included two "V" (Never fumigated) observations misclassified as "N" (not recently fumigated) and three "N" misclassified as "V".
:

- Using additional indicators did not improve rectify misclassification
- Using the first nine PCs of all transformed soil indicators resulted in 10 misclassified observations for the resubstitution method and 19 misclassified observations for the leave-one-out method.

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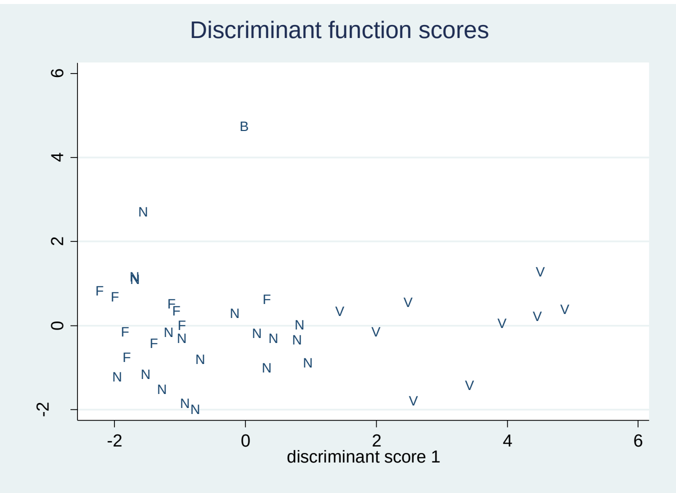


Figure 4.6 Discriminant function scores based on eight soil indicators used to segregate Fumigation categories (bio-fumigation [B]; fumigation [F]; never [V]; not recently [N])

Management practice

Nine soil indicators were required to distinguish among categories of *management practice* (Figure 4.7). These indicators were:

PC_CO2:	principle component derivative of log-transformed (ln_e) measure of CO_2
PC_C_N :	principle component derivative of transformed carbon and nitrogen content
olsen_P_L	log-transformed (ln_e) measure of available phosphorus
PC_Ca_so4:	principle component derivative of transformed calcium and “sum of four” salt content
Mg_L :	log-transformed (ln_e) measure of magnesium
PC_FDA_bf:	principle component derivative of transformed FDA and %BF measures
NO_3_sqrt:	square root transformation of NO_3 content
s_index_sqrt:	square root transformation of S-index
ff_nematodes_L:	log-transformed (ln_e) measure of fungal feeding nematodes

There was misclassification in 2 out of 37 observations: two “cl” (conventionally managed) sites were misclassified as “O” (organic) and “CT” (compost enriched) sites.

The Leave-one-out classification failed to correctly assign 8 out of 37 observations.

- Using additional indicators did not rectify misclassification
- Using the first nine PCs of all transformed soil indicators resulted in 3 misclassified observations with the resubstitution method and 9 misclassified observations with the leave-one-out method.

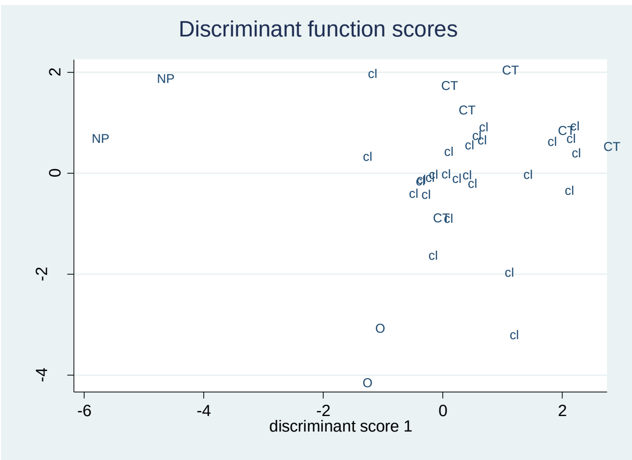


Figure 4.7 Discriminant function scores based on nine soil indicators used to segregate Management categories (non-productive [NP]; compost-enriched [CT]; conventional [cl]; organic [O]).

4.4 Conclusions

The data collected in this benchmarking study indicate that nutrient inputs in Australian vegetable production are largely matched to the crops requirements with the exception of phosphorus and sulphur. Phosphorus and sulphur levels in vegetable growing soils were generally well in excess of crop requirements. The majority of the sites would not have required phosphorous or sulphur application for the crop following sample collection. The levels of more mobile nutrients (i.e. nitrate, potassium) however, differed more than two fold between transplanting and harvest when comparing the mean values and part of the difference may reflect high levels of leaching or losses through N_2O emissions or different levels of uptake by crops at the sites. The levels of these nutrients could not be meaningfully compared across all soils due to the different timing of sample collection (in the cropping cycle).

Predicted estimates of soil indicators derived from regression analysis provided better separation among soil categories than PCA (Principle Component Analysis)-derived soil indicators. Discriminant functions based on current data could predict some but not all soil/management categories successfully.

The greatest number of soil indicators that differed significantly between management occurred for non-production vs conventional production and organic production vs conventional production. Due to the small data set for non-production and organic production soils, these results can only be taken as indications of which parameters would make useful soil indicators but would need to be confirmed in a much larger study.

There were far fewer indicators (total carbon, total nitrogen and respiration) that differed significantly between compost amended and conventional production. Ammonium nitrogen was on the borderline of differing significantly at 5% and would be significant at the 10% level. Due to the larger sample size for the comparison between conventional and compost amended production, these differences are likely to be real differences.

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 practice (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 variables with established acceptable ranges (eg pH, EC, phosphorous, sulphur etc) will be as an indicator set for assessment of soil health.

Appendix 4.1 Benchmarking site details

Site #	Region	Site	Soil type	Crop	Stage of sampling	Farming Practice	Fumigation practice
1	Bairnsdale Vic	Cx W	Loam		No crop	Conventional	Never fumigated
2	Bairnsdale Vic	Cx S	Loam		No crop	Organic	Never fumigated
3	SE Melbourne	TS33TrF	Sand		Transplant	Conventional	Fumigated
4	SE Melbourne	TS33TrNF	Sand		Transplant	Conventional	Non fumigated
5	SE Melbourne	TS33/43	Sand		Native	Non production	Non fumigated
6	SE Melbourne	TS33HarF	Sand		Harvest	Conventional	Fumigated
7	SE Melbourne	TS33HarNF	Sand		Harvest	Conventional	Non fumigated
8	SE Melbourne	TS43TrF	Sand		Transplant	Conventional	Fumigated
9	SE Melbourne	TS43TrNF	Sand		Transplant	Conventional	Non fumigated
10	SE Melbourne	TS43HarNF	Sand		Harvest	Conventional	Non fumigated
11	SE Melbourne	TS43HarF	Sand		Harvest	Conventional	Fumigated
12	SE Melbourne	TS43TrNFC	Sand		Transplant	Conventional	Non fumigated
13	SE Melbourne	TS43TrFC	Sand		Transplant	Conventional	Fumigated
14	SE Melbourne	TS43HarNFC	Sand		Harvest	Conventional	Non fumigated
15	SE Melbourne	TS43HarFC	Sand		Harvest	Conventional	Fumigated
16	Yanco NSW	Yanco 1a	Loam	Wheat		Organic	Non fumigated
17	Yanco NSW	Yanco 1b	Loam	Wheat		Conventional	Non fumigated
18	Yanco NSW	Yanco 2a	Loam	-		Non production	Non fumigated
19	Yanco NSW	Yanco 2b	Loam	cultivated		Conventional	Non fumigated
20	Valla NSW	Yanco3a	Clay			Conventional	Non fumigated
21	Valla NSW	Yanco3b	Clay			Conventional	Non fumigated
22	Bairnsdale Vic	Wg	Loam			Conventional	Non fumigated
23	Bairnsdale Vic	Wg	Loam			Conventional	Biofumigated
24	Tasmania	HF2	Clay	Lettuce	Pre-harvest	Compost	Never fumigated
25	Tasmania	HN3	Clay	Lettuce	Pre-harvest	Compost	Never fumigated
26	Tasmania	HN4	Clay	Lettuce	Pre-harvest	Compost	Never fumigated
27	Tasmania	HS	Clay	Lettuce	Pre-harvest	Conventional	Never fumigated
28	Tasmania	HUnt	Clay	Lettuce	Pre-harvest	Conventional	Never fumigated
29	Boneo, Vic	RL4SGPHar	Sand	Broccoli	Harvest	Conventional	Non fumigated
30	Boneo, Vic	RL4MSHar	Sand	Broccoli	Harvest	Conventional	Fumigated
31	Boneo, Vic	RL4CGWHar	Sand	Broccoli	Harvest	Compost	Non fumigated
32	Boneo, Vic	RL4SGPTrans	Sand	Broccoli	Harvest	Conventional	Non fumigated
33	Boneo, Vic	RL4MSTrans	Sand	Broccoli	Transplanting	Conventional	Fumigated
34	Boneo, Vic	RL4CGWTrans	Sand	Broccoli	Transplanting	Compost	Non fumigated
35	SE Melbourne	PS2UntTrans	Sand	Endive	Transplanting	Conventional	Non fumigated

Site #	Region	Site	Soil type	Crop	Stage of sampling	Farming Practice	Fumigation practice
36	SE Melbourne	PS2CGWTrans	Sand	Endive	Transplanting	Compost	Non fumigated
37	SE Melbourne	PS2DAZTrans	Sand	Endive	Transplanting	Conventional	Fumigated

Appendix 4.2 Transformation functions for normalising the distributions of the measures of soil properties

#	Soil properties	Test of normality for measures of soil properties (p-value)	Transformation function [g(y)]	Test of normality for transformed measures of soil properties (p-value)
1	Labile Carbon	0.054	y^3	0.244
2	CO2_4days	0.019	$\log_e y$	0.223
3	CO2_14days	0.009	$\log_e y$	0.923
4	FDA	0.005	$\log_e y$	0.918
5	%Bacterial Feeders*	0.045	y	0.045
6	%Fungal Feeders	0.042	$\log_e y$	0.449
7	Omnivorous nematodes	<0.001	$\log_e(y+1)$	0.894
8	Predatory nematodes*	<0.001	$1/y^2$	0.026
9	Total nematodes		y	
10	EI	0.222	y	0.222
11	SI	0.027	$1/\sqrt{y}$	0.206
12	CI	0.002	$1/\sqrt{y}$	0.576
13	B/(B+F)	0.034	y^2	0.068
14	NH4	<0.001	$1/\sqrt{y}$	0.509
15	NO_3	0.007	$1/\sqrt{y}$	0.119
16	Total Carbon	0.003	$\log_e y$	0.996
17	Total Organic Matter	0.006	$\log_e y$	0.976
18	Oxidizable Organic Carbon	0.012	$\log_e y$	0.943

19	Oxidizable Organic Matter	0.007	$\log_e y$	0.979
20	Total Nitrogen	0.173	$\sqrt{y}$	0.983
21	EC	0.043	$\sqrt{y}$	0.856
22	%TSS	0.017	$\sqrt{y}$	0.647
23	pH CaCl2	0.882	y	0.882
24	pH water	0.726	y	0.726
25	Ca	0.001	$\sqrt{y}$	0.034
26	%Ca	0.122	y	0.122
27	Ca:Mg	0.357	y	0.357
28	Mg	0.002	$\log_e y$	0.950
29	%Mg	0.025	$\log_e y$	0.361
30	K	<0.001	$\log_e y$	0.070
31	%K	<0.001	$\log_e y$	0.218
32	Available K	<0.001	$1/\sqrt{y}$	0.142
33	Na	0.025	$1/(y+1)^2$	0.131
34	%Na	0.072	$\sqrt{y+1}$	0.277
35	sum_of_4	0.003	$\sqrt{y}$	0.056
36	Available P (Olsen)	<0.001	$\log_e y$	0.083
37	Available S	<0.001	$\log_e y$	0.214
38	Cu	<0.001	$1/\sqrt{y}$	0.049
39	Fe	0.004	$\log_e y$	0.844
40	Zn	<0.001	$\log_e y$	0.328
41	Mn	<0.001	1/y	0.222

Appendix 4.3 Enrichment index (EI) and structure index (SI) for the benchmarking field sites.

Soil sample	Management	Fumigation	Soil type	Timing	EI	SI
Cx W	conventional	never fumigated	silty loam	No crop	58.9	4.5
Cx S	organic	never fumigated	silty loam	No crop	55.7	8.7
TS33transF	conventional	fumigated	sandy	Transplanting	45.4	79.9
TS33transNF	conventional	non fumigated	sandy	Transplanting	85.8	31.5
TS33/43	Non-production	never fumigated	sandy	Native	37.4	26.2
TS33hvestF	conventional	fumigated	sandy	Harvest	62.4	76.5
TS33hvestNF	conventional	non fumigated	sandy	Harvest	73.5	72.4
TS43transF	conventional	fumigated	sandy	Transplanting	84.4	15.7
TS43transNF	conventional	non fumigated	sandy	Transplanting	85.4	22.2
TS43hvestNF	conventional	non fumigated	sandy	Harvest	61.8	71.9
TS43hvestF	conventional	fumigated	sandy	Harvest	38.1	79.2
TS43transNFC	conventional	non fumigated	sandy	Transplanting	93.8	35.8
TS43transFC	conventional	fumigated	sandy	Transplanting	93.0	18.0
TS43hvestNFC	conventional	non fumigated	sandy	Harvest	77.4	77.5
TS43hvestFC	conventional	fumigated	sandy	Harvest	59.8	78.2
Yanco Ag Inst. 1a	organic	non fumigated	sandy/loam		77.3	42.1
Yanco Ag Inst. 1b	conventional	non fumigated	sandy/loam		54.5	8.0
Yanco Ag Inst. 2a	Non-production	non fumigated	sandy/loam		64.2	42.4
Yanco Ag Inst. 2b	conventional	non fumigated	sandy/loam		95.9	53.3
Yanco (Valla) 3a	conventional	non fumigated	loamy clay		91.0	48.0
Yanco (Valla) 3b	conventional	non fumigated	loamy clay		71.1	51.9
Wdglen Nil	conventional	never fumigated	silty loam	Transplanting	92.0	36.3
Wdglen triple-6	conventional	bio fumigated	silty loam	Transplanting	83.7	14.3
Houston F2	compost	never fumigated	loamy clay	Pre-harvest	72.5	35.5
Houston N3	compost	never fumigated	loamy clay	Pre-harvest	63.5	21.4
Houston N4	compost	never fumigated	loamy clay	Pre-harvest	75.2	31.5
Houston S	conventional	never fumigated	loamy clay	Pre-harvest	95.2	48.5
Houston Unt	conventional	never fumigated	loamy clay	Pre-harvest	85.0	36.9
RL4 SGPHvst	conventional	non fumigated	sandy	Harvest	92.7	82.0
RL4 MS Hvst	conventional	fumigated	sandy	Harvest	91.9	86.6
RL4 CGW Hvst	compost	non fumigated	sandy	Harvest	93.2	83.3
RL4 SGPTrans	conventional	non fumigated	sandy	Transplanting	91.1	65.9
RL4 MS Trans	conventional	fumigated	sandy	Transplanting	94.4	67.8
RL4 CGW Trans	compost	non fumigated	sandy	Transplanting	95.3	61.4
PS 2 UNT Trans	conventional	non fumigated	sandy	Transplanting	95.6	63.9
PS 2 CGW Trans	compost	non fumigated	sandy	Transplanting	96.8	59.3
PS 2 DAZ Trans	conventional	fumigated	sandy	Transplanting	96.1	42.7

5 Influence of Soil Health Practices on Soil-borne Pathogens and Diseases of Vegetables under Controlled Conditions

5.1 Industry Summary

Pesticide withdrawals and increased consumer demand for produce with minimal chemical inputs are placing pressure on growers to adopt alternatives for managing soil-borne diseases in vegetable crops. Growers are considering better ways of managing soil health for more sustainable cropping production. Amending soils with carbon inputs, such as green manures, animal manures, composts and other carbon inputs, has the potential to both improve soil health and increase disease suppression. In the past, however, inconsistent results with carbon amendments in soil have limited their use for disease control purposes. A series of glasshouse and laboratory trials were conducted under controlled conditions to investigate the effect of amending soils with different carbon inputs against specific diseases of vegetable crops.

Of the carbon amendments investigated:

- Compost and humate showed the greatest potential for suppressing (by up to 60%) damping-off of radish caused by *Rhizoctonia solani*. Adding some forms of biochar (those produced from rice hulls) to soil increased damping-off.
- Carbon amendments that reduced soil pH, such as lignite, increased the expression of clubroot in brassicas. These amendments may require reformulation or co-application with lime in areas where clubroot is a problem. In contrast, compost increased soil pH and biological activity, and suppressed clubroot expression compared with other carbon amendments.
- Vetch and biochar showed potential for accelerating the degradation (up to 40% greater after 1-month) of survival structures (sclerotia) of *Sclerotinia minor* (the cause of lettuce drop) in soil.

Scientifically, a relationship was shown whereby adding active or ‘labile’ carbon to soil increased soil biological activity. It is thought that increasing biological activity in soil may be important in generating disease suppression through a process called ‘antagonism’ against pathogens. Therefore, measuring soil biological activity after amending soils with carbon inputs could be one important indicator for predicting disease control in the field. However, more research is required to better understand the mechanisms (eg the biological and chemical shifts in soil) of disease suppression by carbon amendments to give growers more reliable disease control systems. This will require further research investment by industry, but ultimately the benefits will include: increased sustainability of production, more reliable disease control with reduced pesticide inputs, and increased carbon sequestration into soils.

5.2 Introduction

Soil-borne pathogens cause large crop and financial losses ($100-150M) in the Australian vegetable industry (Porter et al., 2007). Over the past decade, the need to find new sustainable practices to control them has increased dramatically. Regulations on pesticides worldwide, particularly fumigant chemicals, are becoming increasingly prohibitive to their use due to increased concerns over their negative effects on the environment, humans and food. Additionally, in some vegetable growing regions, overuse of individual pesticides has led to their reduced effectiveness due to: enhanced degradation by soil microbes (Matthiessen, 2003), development of pesticide resistance in pathogen populations (Russell, 1995), and reduced soil resilience following a decline in biodiversity and activity of soil biota (Albiach et al., 2000). Industries that were once highly dependent on pesticide use, such as the vegetable industry, are starting to realise that greater ecological balance is required in their soils in future farming systems. This is driving advancements in the use of organic amendments to not only improve soil health, but also improve disease suppression (Weller *et al*., 2002; Mazzola, 2004; Janvier *et al*., 2007).

Prior to the use of pesticides, crop rotation and organic amendments of green and animal manures formed important components of management systems to control soil-borne diseases in the vegetable industry (De Ceuster and Hoitink 1999). However, organic amendments did not control pathogens as consistently as pesticides, and this restricted their ongoing use (Bonanomi et al., 2010). Some organic amendments can decrease soilborne diseases, either by the action toxins produced during the breakdown of organic products against pathogens (Lazarovits, 2001) or by manipulation of the soil microflora that suppress pathogens and disease (Akhtar and Malik, 2000; Mazzola, 2002). Equally, however, other researchers have shown that incorporation of organic amendments into soil can increase disease (Abaswi and Widmer, 2000; Termorshuizen et al. 2006), especially with pathogens that can use carbon as a food source (saprophytes) and when organic residues are not fully decomposed. For example, incorporation of hardwood composts into soils has reduced *Pythium* and *Phytophthora* spp. pathogens (Hoitink and Fahy, 1986), while composts that increase soil pH have reduced clubroot caused by *Plasmodiophora brassicae* (Noble and Coventry, 2005). High C:N ratio amendments (e.g. sawdust, grass hay and sugar cane trash) have reduced populations of specific nematodes through biological shifts (Stirling et al., 2005), whereas high nitrogen amendments have little effect on parasitic nematodes, but have controlled *Streptomyces* and *Verticillium* spp. (Lazarovits, 2001; Oka, 2010). The common understanding in these examples is that organic amendments tend to increase labile carbon, microbial activity and diversity, and that this can drive disease suppression.

For vegetable growers to again widely adopt organic amendments for disease management they need greater certainty of their effect. This will require greater knowledge of: (1) the mechanisms that drive disease suppression by organic amendments; and (2) the impact of specific amendments on specific crop/pathogen systems under specific environments and soil types. This section describes a series of pot and laboratory trials aimed at investigating the effects of incorporating common organic amendments into sandy soils on crop/pathogen systems under controlled conditions. Overall, the experiments aim to test the hypothesis that organic amendments increase labile carbon and biological activity, which drives suppression of vegetable diseases.

5.3 General Materials and Methods

5.3.1 Organic Amendments

The following organic amendments were investigated in pot trials:

Biochar

Biochar is produced by pyrolysis, a system of low-temperature burning in the presence of low oxygen, in which organic matter is reduced to charcoal (Lehmann, 2007). Biochar can be produced from different organic parent materials (e.g. green waste, wood chips, chicken manure, rice hulls). Biochar presents industry with an opportunity for sequestering carbon into soil, in addition to improving soil health, because it breaks down much more slowly than other organic amendments. Biochars may improve the chemical, physical and biological characteristics of soil, but their effects on soil-borne pathogens have not been thoroughly investigated (Van Zwieten, 2010).

Biochar used in trials was supplied by BEST Energies Australia (parent material: hardwood chips) or Australian Biochars (parent material: rice hulls).

Compost

Compost is partially decomposed organic matter produced by microorganisms. In vegetable systems, compost can improve soil health, reduce water and fertiliser requirements, reduce nutrient run-off and erosion, and increase crop yields (Wilkinson et al., 2000). Additionally incorporation of compost into vegetable soils may suppress disease by stimulating antagonistic or antibiotic-producing microflora, inducing systemic resistance in the crop (Hoitink and Boehm, 1999), or through alterations to soil pH (Noble and Coventry, 2005).

Compost used in trials was supplied by Pinegro Products and was produced from municipal green waste using processes complying with Australian standard AS4454.

Humate

Humates (oxidised lignite) are the compounds arising from highly decomposed organic materials found in areas where coal is mined. They are separated into three constituents based on their solubility – humic acids, fulvic acids and humin. Humates are implicated as organic amendments that improve soil health and aggregate formation (Pena-Mendez et al., 2005), and are widely promoted for use in the vegetable industry.

Humate used in trials was supplied by Lawrie Co.(SA), and contained 70% humic acid in a granulated formulation.

Lignite

Lignite is soft brown coal, being an intermediary between peat and bitumous coal. It has a high cation exchange capacity and has been reported to improve soil health (Hendrick and Black, 2002). The impact of lignite as a soil amendment has not been thoroughly investigated for vegetable systems.

Lignite used in trials was supplied by Debco (Vic).

Vetch

Rotation with vetch (*Vicia* spp.) may increase soil nitrogen, suppress weeds, and improve soil structure. Research shows that incorporation of vetch residues into vegetable soils can suppress some fungal pathogens, but promote disease caused by parasitic nematodes (Abawi and Widmar, 2000). Vetch produces a range of allelochemicals (e.g. cyanamides; Kamo et al., 2003) that may directly reduce inoculum of fungal pathogens.

Vetch residues used in trials were grown from seed (supplied by Grahams Seeds, Vic) in the field for 6 weeks. Plant residues were coarsely chopped and air dried prior to incorporation into soil.

5.3.2 Incorporation of organic amendments

Samples of the organic amendments were sent to the DPI State Chemistry Laboratories, Werribee to measure their carbon, nitrogen, and water contents using standard techniques (Table 5.1).

Table 5.1 Carbon, nitrogen and moisture contents (%) of organic amendments.

Substrate	Carbon	Nitrogen	Moisture
Biochar	65.6	0.25	1.3
Compost	19.5	2.01	61.5
Humate	46.6	1.12	4.9
Lignite	62.3	0.71	47.8

Except where otherwise stated, amendments were thoroughly mixed into soil at equivalent rates of carbon (6 - 8 mg C / g of dry soil). This rate corresponds to commercial application of biochar (10 t/ha) when mixed into soil to a depth of 10 cm (eg Table 5.2). The addition of nitrogen by the different amendments was balanced to an equivalent rate (0.8 -0.9 mg N/g dry soil) by adding appropriate amounts of potassium nitrate (selected as a non-acidifying N source). Finally, the volume of the amendment mixed into soil was balanced (150 – 160 mL/L of soil) by adding appropriate amounts of sterile river sand. This was to ensure that the amount of pathogen inoculum in the soil was not diluted unevenly when adding the amendments.

Table 5.2 Rates of amendments added to field soil in the *Brassica* / *Plasmodiophora* experiment (Section 2.5). These rates were equivalent to 8 mg C/g dry soil.

Amendment	Amendment added (g/pot)	Equivalent field rate (t/ha) when incorporated to a soil depth of 10 cm
Biochar	10	10
Compost	87	85
Humate	8	15
Lignite	16	20
Non-amended control	-	-

5.3.3 Key soil health measurements

Labile Carbon

Labile carbon includes the carbon fraction in soil that is readily available for breakdown by soil microorganisms (Janvier et al. 2007), (i.e. turns over in less than 5 years). As such it is a more sensitive indicator of soil health and function than measurement of other inert carbon fractions (Hoyle et al., 2010). Labile carbon was measured using the method described by Weila et al. (2003) based on the oxidisation rate of potassium permanganate by active carbon.

Microbial Activity

Soil microbial activity was measured using the method described by Schnurer and Rosswall (1982) based on the hydrolysis of fluorescein diacetate. This assay relates to the presence of universal enzymes (e.g. lipases, proteases, etc) of biological origin and function in soil.

pH

Soil pH was measured in de-ionised water using standard techniques.

5.4 Expression of Damping-Off in Radish in Carbon-Amended Soil

5.4.1 Introduction

Rhizoctonia solani is one of the most important casual agents of damping-off and other soil-borne diseases in vegetable crops (including Brassicas, beans, lettuce, carrot, potato and onion) in Australia (Donald et al., 2010). In addition to its pathogenicity, *R. solani* also has a high competitive saprophytic ability, allowing it to survive in soils by utilising organic matter as a nutrient source (Guijarro et al., 2010). For this reason, *R. solani* represents an important model pathogen to understand the effects of carbon amendments on disease expression.

Trials aimed to investigate the use of carbon amendments in soils to suppress damping-off in radish caused by *Rhizoctonia solani* AG 2.1.

5.4.2 Methods

Two glasshouse trials were conducted: one in sterile potting media (Debco), the other in a sandy loam soil collected from a commercial vegetable farm in Devon Meadows, Victoria (38º10’56.45’’S, 145º19’34.10’’E).

Inoculation

In both trials, all media and soil was inoculated with two isolates of *Rhizoctonia solani* AG 2.1 known to be pathogenic in radish. The pathogen isolates were grown on water agar plates, combined in equal proportions, blended with water, and used to inoculate media or soil at rate of 0.5 plates / kg soil.

Carbon Amendment Treatments

In the potting media trial, carbon amendments treatments consisted of: biochar (parent material: rice hulls) and compost. In the soil trial, carbon amendment treatments included: biochar (parent material: hardwood chips), compost, lignite, and humate. All carbon amendments were applied at an equivalent rate of 6.5 mg C / g media or soil.

Controls consisted of fumigated media or soil (dazomet, 10 mg/g soil), and untreated media or soil.

Planting

After a two week ‘resting’ period, the media or soil was potted up (16.5 cm diameter pots), sown with 10 seeds/pot of radish cv. French Breakfast, and maintained at close to field capacity water in a glasshouse.

Three weeks after sowing, the radish seedlings were harvested and assessed for the incidence of damping-off symptoms. Koch’s postulates were performed to confirm that the damping-off was caused by *Rhizoctonia solani* AG 2.1.

Following harvest, the same soils were re-potted and re-sown with radish. There were three sequential rotations of radish in both trials (total of nine weeks).

Measurements

In addition to disease incidence, microbial activity (FDA), pH, and concentration of *R. solani* in soil (DNA concentration using qPCR) were measured at sowing and at harvest in the soil trial.

Design

Both trials were conducted as randomised complete block designs. There were four blocks in the potting media trial, and six blocks in the soil trial. There was one pot per treatment per block.

5.4.3 Results

Potting media trial

Amending media with biochar (parent material: rice hulls) increased disease incidence significantly compared with the untreated control (Figure 5.1). This effect became more marked as the rotations progressed, and by the third rotation disease incidence was 6-fold higher in biochar-amended media than in the untreated control.

Disease incidence in compost-amended media was statistically equivalent to that in the untreated control. Overall, disease incidence in compost-amended and untreated media decreased as the rotations progressed.

Fumigation with dazomet reduced disease incidence to low levels. However, the trend was for disease incidence to increase in dazomet-treated media as the rotations progressed.

Soil trial

Soil pH, microbial activity (Figure 5.2) and *R. solani* concentration increased over time, compared with the controls, in all carbon amendment treatments. By the third rotation, there was 378 - 680 pg *R. solani* DNA / g soil in the carbon amendment-treated soils, significantly higher than 123 *R. solani* DNA / g soil in the untreated control. Despite this, a trend towards disease reduction was apparent in radish grown in carbon amendment treatments, in some cases significantly (Figure 5.3). For example, humate was phytotoxic to radish two weeks after incorporation, but by the third rotation, it significantly reduced disease. For compost, however, disease reduction occurred in the second rotation but was not carried into the third rotation.

Details of the effects of carbon amendments on disease incidence (Figure 5.3) are as follows:
In rotation 1, humate was phytotoxic and all seedlings died. Disease incidences in the control and compost treatments were significantly higher than the dazomet treatment. Disease incidences in the biochar and lignite-amended soils were in between the control and dazomet.

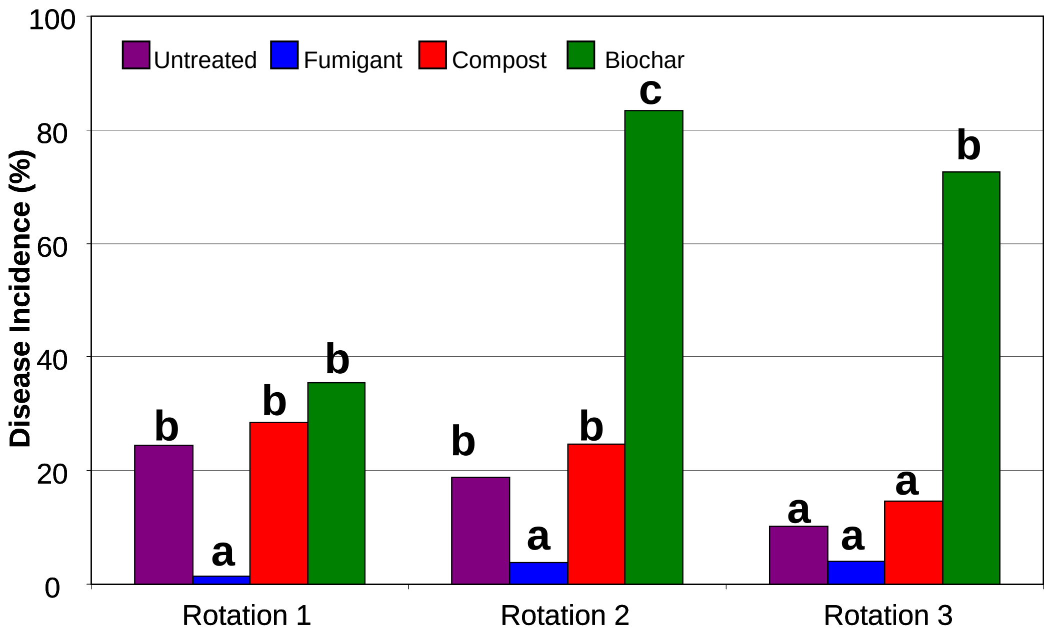


Figure 5.1 Incidence of damping-off in radish seedlings grown in potting media inoculated with *Rhizoctonia solani* AG2.1 and amended with various carbon inputs. Columns followed by different letters within each rotation are significantly different where p = 0.05.

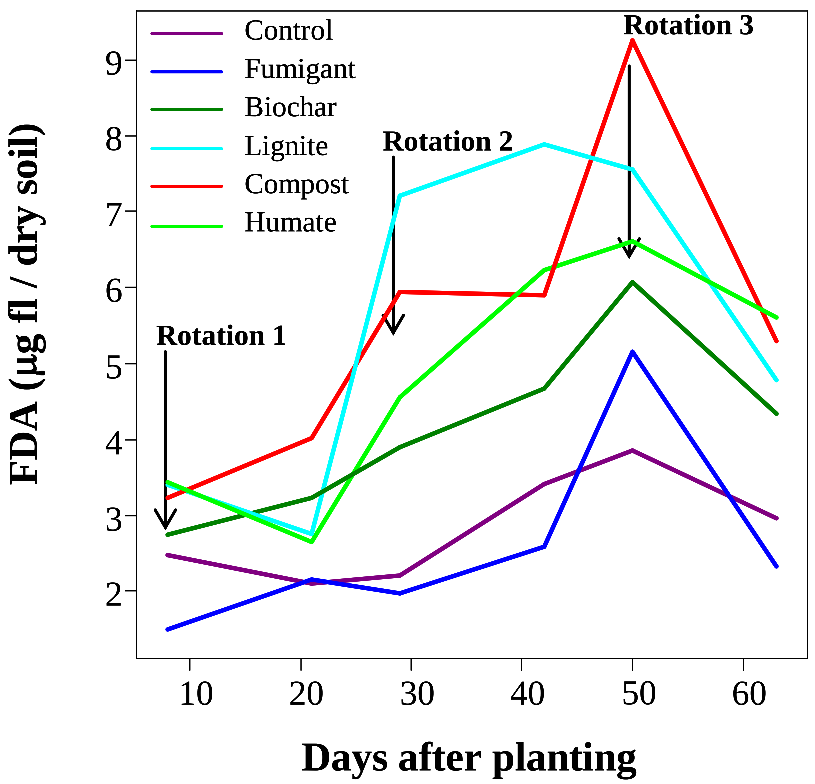


Figure 5.2 Microbial activity (FDA hydrolysis) in *R. solani*-inoculated soils treated with carbon amendments. Microbial activity increased with time, and soils treated with carbon amendments tended to have higher activity than untreated or fumigated soils.

By rotation 2, humate was no longer phytotoxic. Disease incidences in the compost and dazomet treatments were significantly less than the control. Once again, disease incidences in the biochar, lignite and humate-amended soils were in between the control and dazomet.
By rotation 3, disease incidences in the humate and dazomet treatments were significantly less than the control. However, in the compost and lignite treatments, disease incidence had increased again to the level of the control. Disease incidence in biochar-amended soil remained in between the control and dazomet.

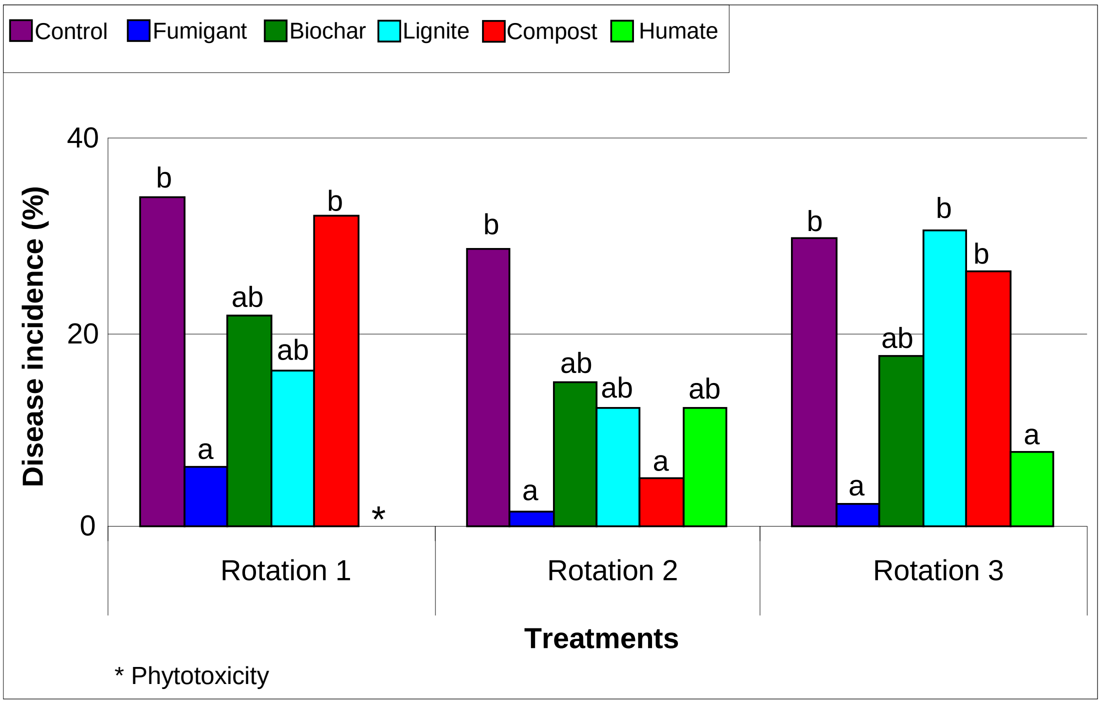


Figure 5.3 Incidence of damping-off in radish seedlings grown in soils inoculated with *Rhizoctonia solani* AG2.1 and amended with various carbon inputs. Columns followed by different letters within each rotation are significantly different where p = 0.05.

5.4.4 Discussion

Trials showed that carbon amendments can have two simultaneous and opposing effects on *R. solani* and damping-off:
To increase the concentration of the R. solani pathogen in soil. In addition to its pathogenicity, *R. solani* also has a high competitive saprophytic ability, allowing it to survive in soils by utilising organic matter (particularly cellulose-rich substrates; Termorshuizen *et al*., 2006) as a nutrient source. Therefore, the ability of *R. solani* to proliferate in soils amended with carbon inputs in the current trials was expected.
To suppress damping-off disease caused by R. solani. Carbon amendments increased the concentration of *R. solani* in soil, but this did not generally translate into increased disease incidence. Instead, a trend towards disease reduction was apparent, in some cases significantly. The level of disease reduction depended on both the type of carbon amendment, growth media and time. Disease suppression by the carbon amendments in these trials is probably due to an increase in specific groups of soil

microflora that interfere with pathogenesis through antagonism (Mazzola, 2002). This is supported by results showing that carbon amendments generally increased biological activity in soil.

Of the amendments investigated, compost and humate (provided it is applied at rates that do not cause phytotoxicity) showed the greatest capacity for suppression of damping-off, followed by biochar derived from wood chips and lignite. The effect of biochar on disease incidence differed depending on its parent material and the growing media. This effect is consistent with the literature, which shows parent material can greatly affect the chemistry and yield response of crops grown in soils amended with biochar (Sohi et al., 2009). The soil fumigant, dazomet, generally provided better disease control than the organic amendments used in the current trials. However, in one trial, the trend was for disease to increase in fumigated media as time progressed. This is consistent with the hypothesis that fumigation reduces a soil's resilience to pathogen re-colonisation (Porter et al., 2005), and may cause disease build up over time.

The challenge for science is to further identify carbon amendments that: (1) minimise the increase in concentration of *R. solani*, and (2) maximise the disease suppressive effect. This will require greater knowledge of the mechanisms driving these processes, but will allow growers to better manipulate soils for more reliable management of diseases caused by *R. solani*.

5.5 Expression of Clubroot in Brassicas in Carbon-Amended Soil

The trials in this section were conducted as an undergraduate student project by Ms Lynda Hanlon under the supervision of the project team and Dr Tony Weatherley (University of Melbourne).

5.5.1 Introduction

The pathogen *Plasmodiophora brasssicae* causes clubroot disease in brassica vegetable crops, including broccoli, Brussels sprouts, cabbage, Asian greens and turnip (Donald and Porter, 2009). Losses to clubroot in the Australian vegetable industry are estimated at $5-15 M pa, depending on seasonal effects and the use of properly implemented controls (Porter et al., 2007). There are no brassica varieties truly resistant to *P. brassicae*, and growers' reliance on continuous cropping and short rotations has increased inoculum loads in soils supporting brassica production (Donald and Porter, 2009). The pathogen can survive as resting spores for 18+ years even without a host present (Wallenhammar, 1996), but the role of organic amendments in suppressing or enhancing expression of clubroot has not been thoroughly investigated. In contrast, soil factors are known to greatly influence the expression of clubroot, with acidic soil of pH less than 7, high soil moisture, and temperatures between 20-25ºC conducive to infection (DPI, 2005).

Trials aimed to investigate the use of carbon amendments in soils to suppress clubroot in brassicas caused by *Plasmodiophora brassicae*.

5.5.2 Methods

Two glasshouse trials were conducted simultaneously: one on Chinese cabbage (*Brassica rapa* subsp. *pekinensis*, var. Green Rocket) the other on broccoli (*Brassica oleracea*, var. Viper), both of which are susceptible to *P. brassicae*.

Soil

Sandy loam soil was collected from a vegetable farm in Boneo, Victoria (38º24’10.29’’ S, 144º54’07.91’’ E) with a history of clubroot in the preceding broccoli crop. Presence of *P. brassicae* in the soil had previously been confirmed by PCR techniques.

Carbon Amendment Treatments

In both trials, carbon amendment treatments consisted of: biochar (parent material: hardwood chips), compost, humate and lignite. All carbon amendments were applied at an equivalent rate of 8 mg C / g soil (Table 2.2). The control consisted of untreated soil.

Planting

Soils were potted up (12 cm diameter pots) either 7 days (broccoli) or 15 days (Chinese cabbage) after incorporation of the carbon amendments. Five seeds of Chinese cabbage or broccoli were sown into pots and seedlings thinned to two plants/pot at 14 days after sowing. Pots were maintained in a glasshouse at near field capacity until harvest. Chinese cabbage plants were harvested at 86 days after sowing (91 days after incorporation of the amendments), and broccoli plants were harvested at 112 days after sowing (119 days after incorporation of the amendments).

Measurements

Soil labile carbon, biological activity and pH were measured at planting, and at each of the harvests as previously described.

At harvest, soil was washed from roots and the severity of clubroot assessed using the 1-9 scale of Donald et al. (2004). Plant biomass was measured by drying roots and shoots in an oven at 80ºC for four days and then weighing them.

Design

Both trials were conducted as randomised complete block designs. There were six blocks in each trial, and one pot per treatment per block.

5.5.3 Results

Labile carbon

At planting (7 days after incorporation of amendments), labile carbon had increased in compost-amended soils by almost 200% compared with untreated soils. Similarly, labile carbon in lignite, biochar and humate-amended soils had increased it by approximately 100% (Figure 5.4a).

At the cabbage harvest (91 days after incorporation of amendments), labile carbon remained higher in compost, lignite and humate-amended soils than in the untreated soil. However, labile carbon in biochar-amended soil was equivalent to that in untreated soil (Figure 5.4b). A similar pattern in results (Figure 5.4c) occurred for labile carbon at the broccoli harvest (119 days after incorporation of amendments).

Overall, there was a trend towards reduced labile carbon in amended soils over time (Figure 5.4).

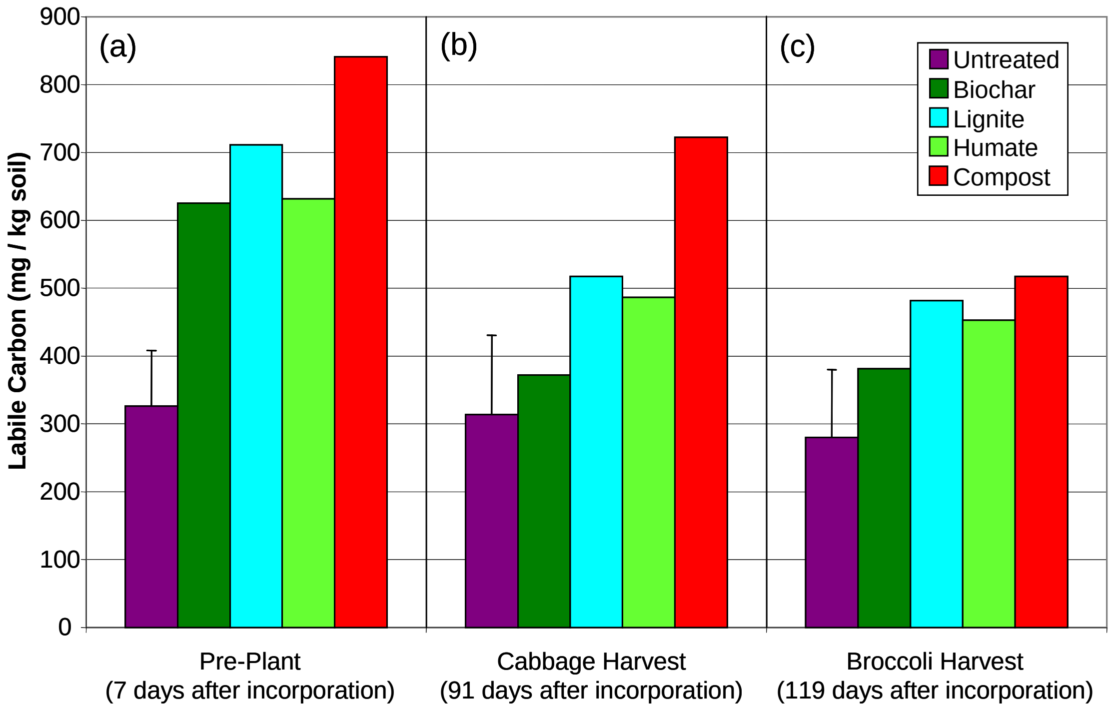


Figure 5.4 Labile carbon in potted soils amended with various carbon inputs at: (a) planting (7 days after incorporation of the amendments), (b) cabbage harvest (91 days after incorporation of the amendments), and (c) broccoli harvest (119 days after incorporation of the amendments). Error bars for each measurement period are least significant differences where p = 0.05.

Biological activity

There was no significant difference in biological activity between treatments (Figure 5.5a) at planting (7 days after incorporation of amendments).

At cabbage harvest (91 days after incorporation of amendments), biological activity was significantly higher (by 200% compared with the untreated control) in the compost-amended soil compared to all other treatments (Figure 5.5b). By the broccoli harvest (119 days after incorporation of the amendments), biological activity was 250% higher in compost-amended soils than in the control (Figure 5.5c).

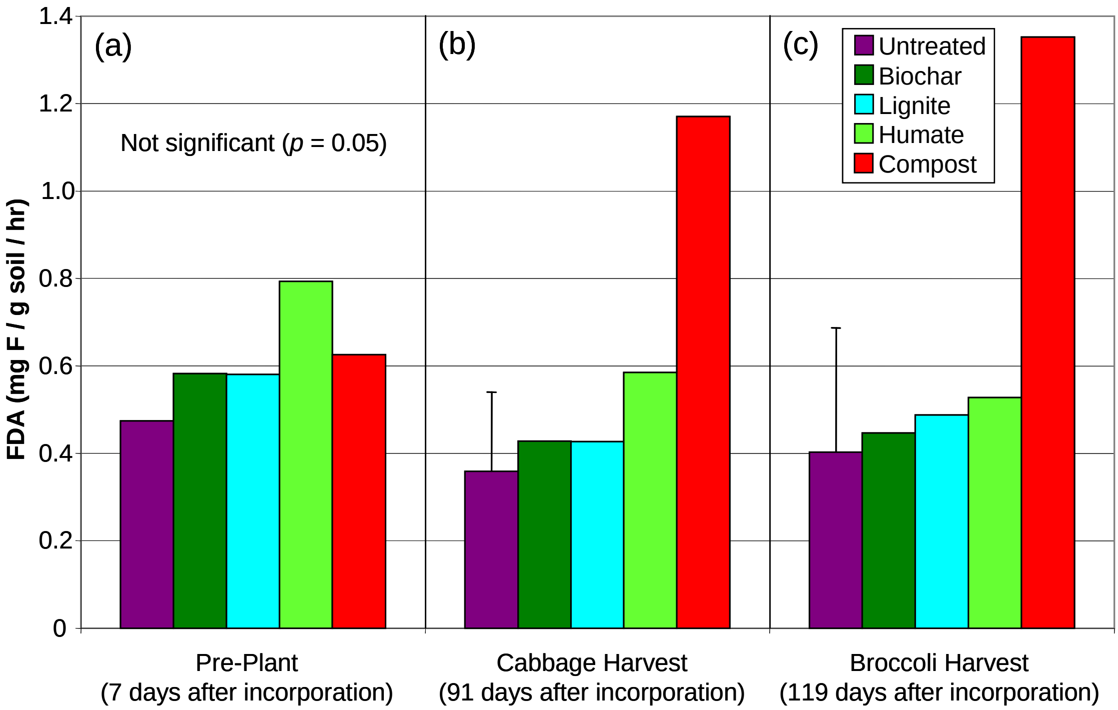


Figure 5.5 Biological activity (FDA hydrolysis) in potted soils amended with various carbon inputs at: (a) planting (7 days after incorporation of the amendments), (b) cabbage harvest (91 days after incorporation of the amendments), and (c) broccoli harvest (119 days after incorporation of the amendments). Error bars for each measurement period are least significant differences where p = 0.05.

Soil pH

The addition of humate and compost significantly increased soil pH at planting (Figure 5.6a). At the cabbage harvest, the pH of lignite-amended soils was reduced significantly compared with the control, while compost-amended soils averaged the highest pH (Figure 5.6b). A similar trend in occurred in soil pH at the broccoli harvest (Figure 5.6c).

Overall, there was a trend towards reduced soil pH over time (Figure 5.6).

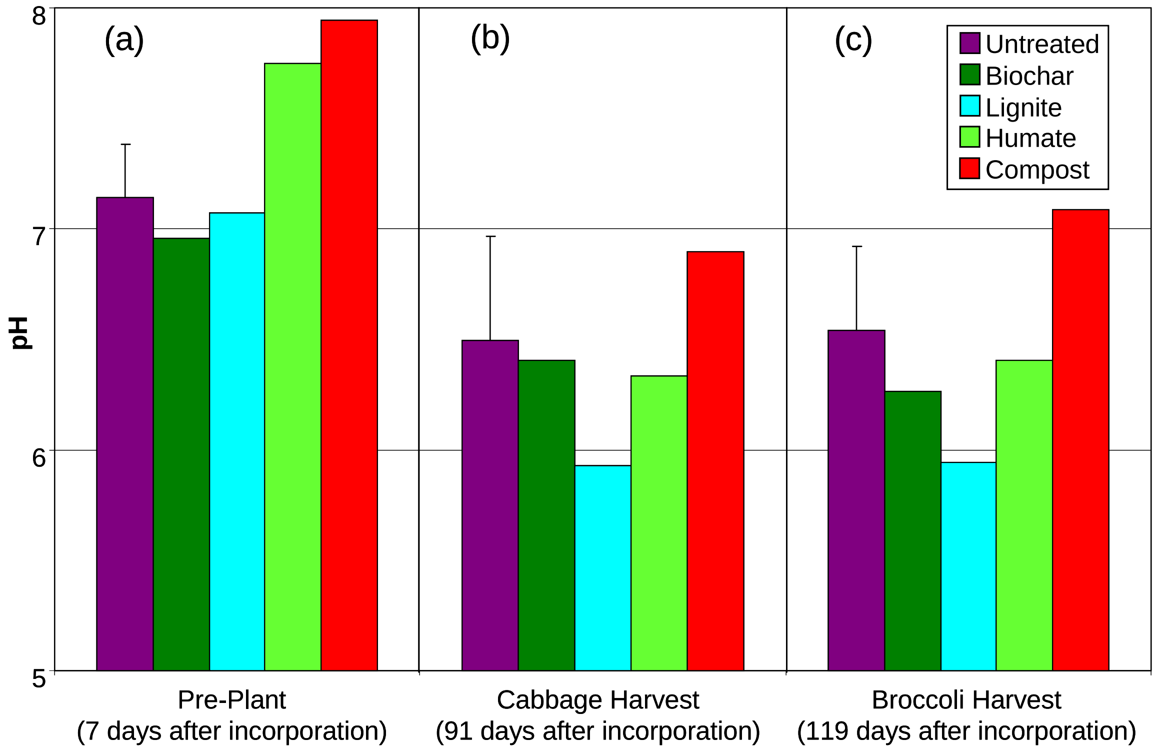


Figure 5.6 pH in potted soils amended with various carbon inputs at: (a) planting (7 days after incorporation of the amendments), (b) cabbage harvest (91 days after incorporation of the amendments), and (c) broccoli harvest (119 days after incorporation of the amendments). Error bars for each measurement period are least significant differences where p = 0.05.

Clubroot Severity

No significant root galling occurred in the Chinese cabbage crop. However, when roots were stained with phloxine to examine for zoospores, microscopic examination showed evidence of minor infection of the root hairs.

In the broccoli trial, clubroot severity was significantly higher in plants grown in soils amended with lignite compared with those grown in untreated and compost-amended soils (Figure 5.7). Clubroot severity was higher in plants grown in soils amended with biochar and lignite, compared with untreated soils. However, this was only significant at the $p = 0.10$ level, and not at the $p = 0.05$ level.

Biomass

There was no difference in the biomass of Chinese cabbage (Figure 5.8) and broccoli (Figure 5.9) between treatments.

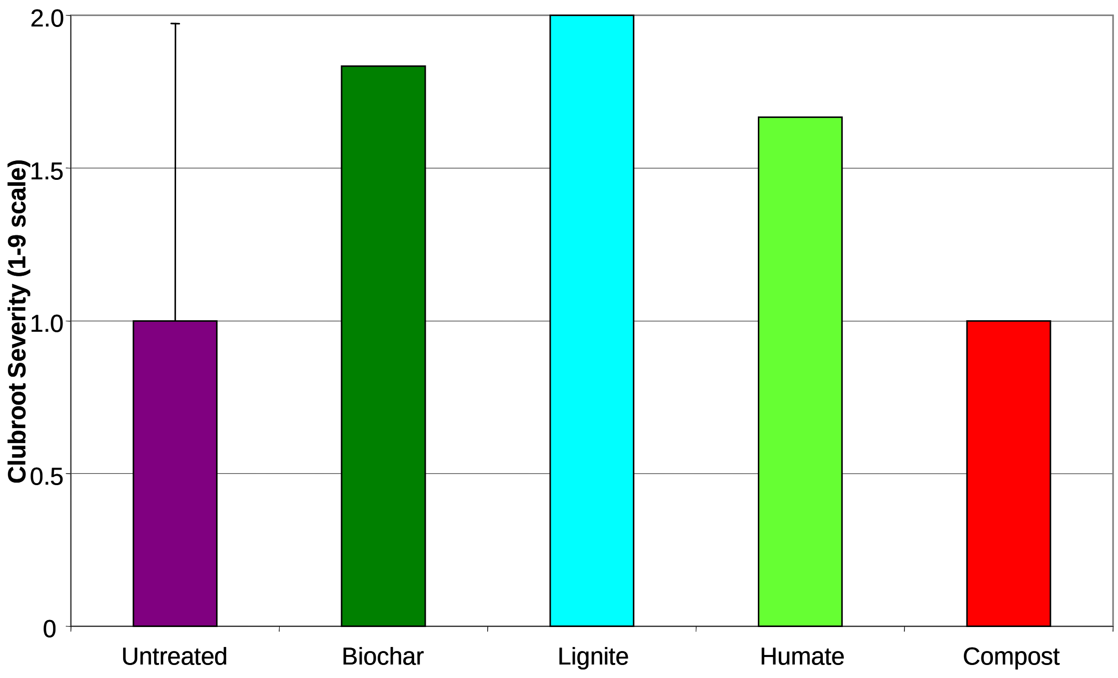


Figure 5.7 Clubroot severity in broccoli grown in potted soils amended with various carbon inputs (119 days after incorporation of the amendments, 112 days after sowing). The error bar is the least significant difference where p = 0.05.

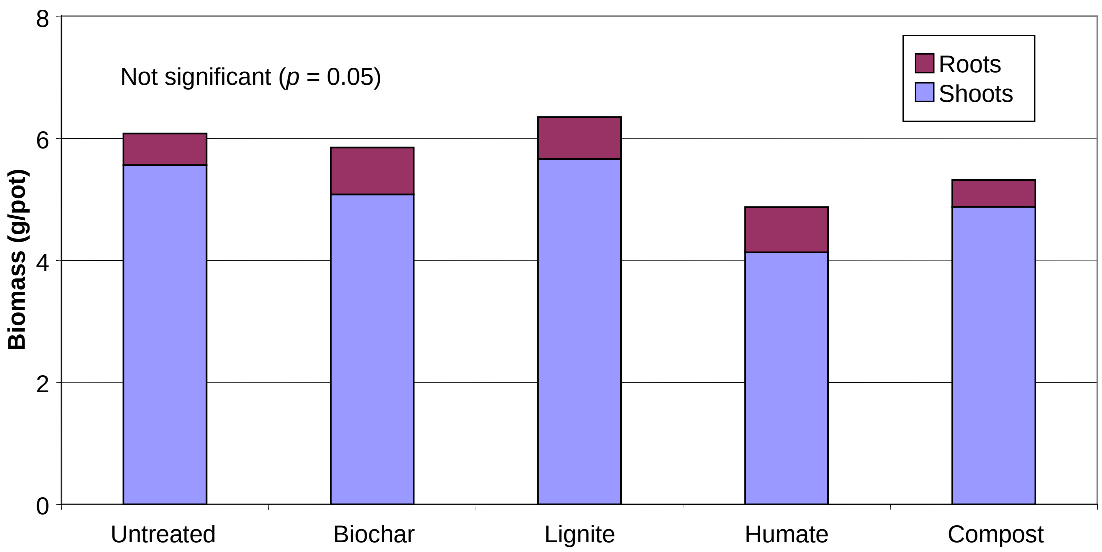


Figure 5.8 Biomass of Chinese cabbage grown in potted soils amended with various carbon inputs (84 days after sowing, 91 days after incorporation of the amendments).

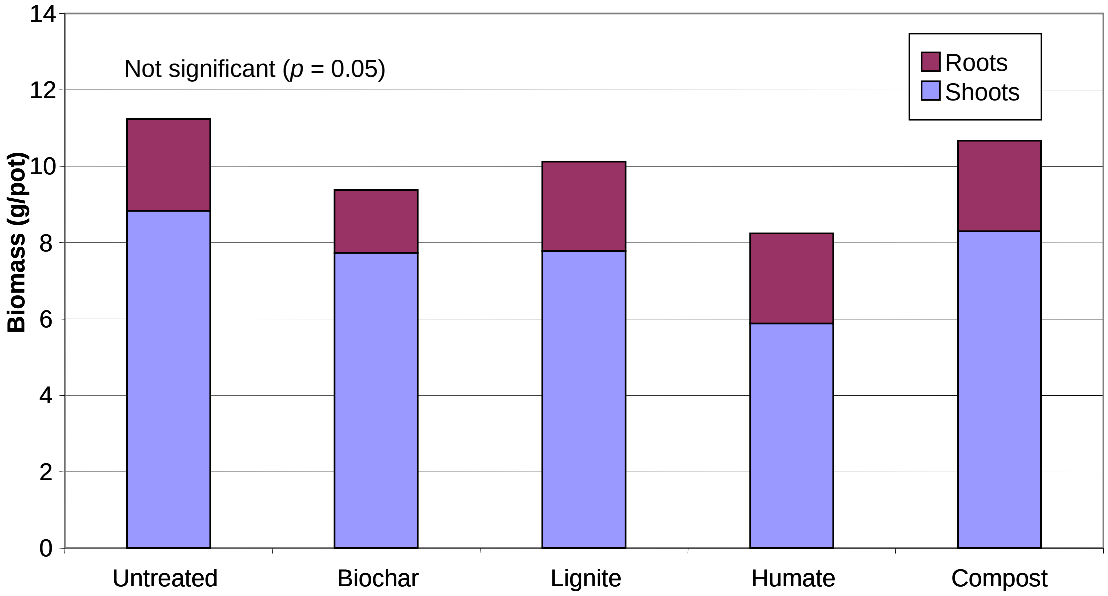


Figure 5.9 Biomass of Broccoli grown in potted soils amended with various carbon inputs (112 days after sowing, 119 days after incorporation of the amendments).

5.5.4 Discussion

These trials provided evidence that carbon amendments may affect clubroot expression in brassicas by: (1) modifying soil pH, and (2) increasing biological activity in soil.

The trials showed that amendments that lowered pH, such as lignite, increased expression of clubroot in broccoli. In contrast, broccoli grown in compost-amended soils, which raised soil pH, showed no symptoms of clubroot. This is consistent with research in the literature that shows that the ability of compost amendments to suppress clubroot largely depends on their effect in increasing soil pH (Noble and Coventry, 2005). The strong relationship between pH and clubroot expression suggests that some carbon amendments may need reformulation or co-application with lime to prevent soil acidification, especially in areas where clubroot is a problem.

The trials also demonstrated that adding carbon inputs to soil can increase labile carbon and biological activity. There was a significant association whereby soil biological activity increased as labile carbon in soil increased (Figure 5.10). For example, amending soils with compost increased labile carbon by 2-fold and this in turn increased biological activity by 3-fold. The direct effect of increased biological activity in soil on disease expression was difficult to isolate in these trials. This is because pH varied at the same time as biological activity in amended soils. However, it is possible that the increased biological activity in compost-amended soils contributed to clubroot suppression in broccoli, perhaps through increased antagonism by microorganisms against *P. brassicae*. It is also possible that other carbon amendments with higher labile carbon contents (e.g. green manures, crop mulches) may increase biological activity and disease suppression more than compost. This hypothesis is supported by field trial results from this project showing that amending soil with silage reduced clubroot expression in broccoli to a greater extent than did compost addition (Section 6.5).

Overall, the compost amendment showed the greatest potential for suppressing clubroot compared with the other carbon amendments investigated in these trials. This is probably through its combined effects of raising pH and increasing biological activity.

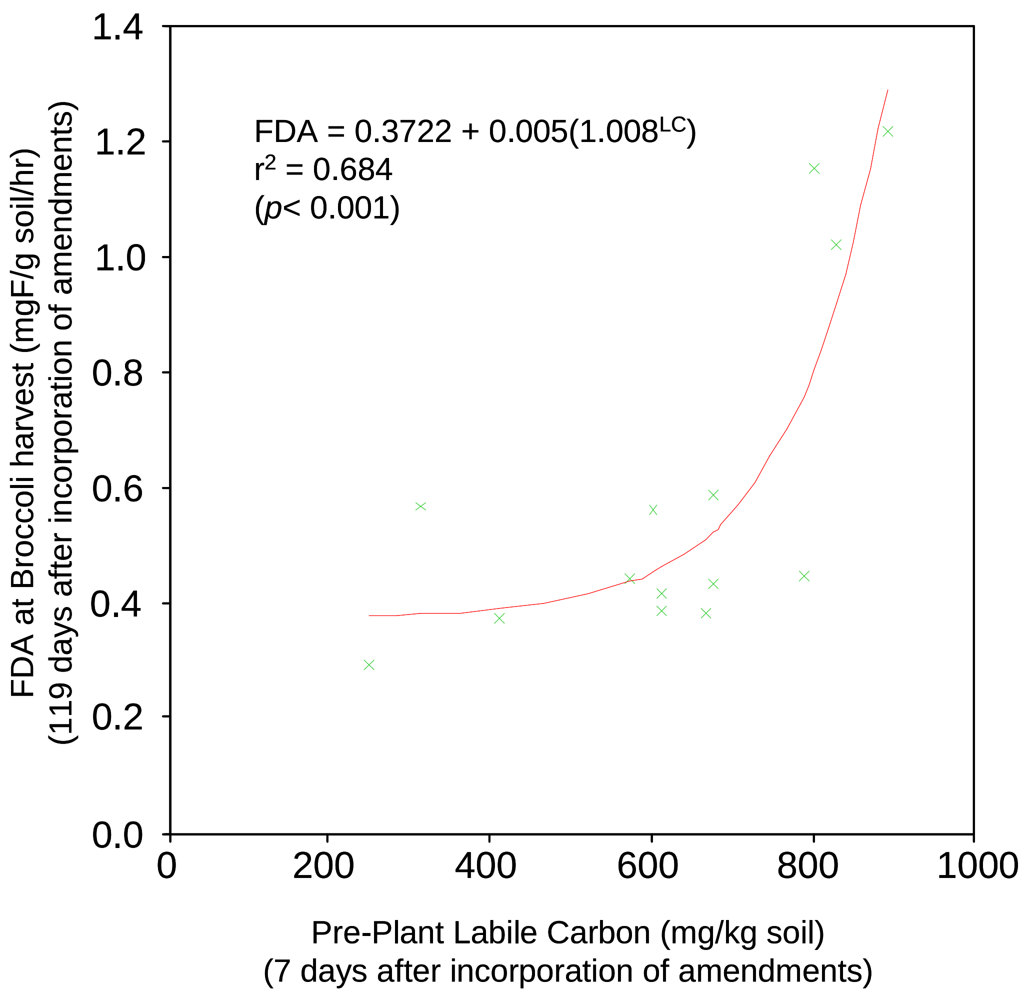


Figure 5.10 Relationship between labile carbon and soil biological activity in soil.

5.6 Degradation of Sclerotia of Sclerotinia minor in Carbon-Amended Soils

5.6.1 Introduction

Sclerotinia diseases cause significant yield and income losses to vegetable growers in all states of Australia, particularly in lettuce and green bean crops (Porter et al., 2007). They are caused by two soilborne pathogens, *Sclerotinia minor* and *S. sclerotiorum.* Both pathogens have a broad host range and can form survival structures called sclerotia that persist in soil for many years. Limited chemical control options are available in the market for Sclerotinia diseases, especially to reduce pathogen carry-over (sclerotia) in heavily infested soils (Villalta et al., 2010). There is also little knowledge on the effect of different carbon amendments on the persistence of sclerotia of *Sclerotinia* spp. in Australian vegetable soils.

This trial aimed to investigate the ability of carbon amendments to accelerate degradation of sclerotia of *S. minor* in soil.

5.6.2 Methods

Treatments: Soil history

Sandy loam soils were collected from a vegetable farm in Devon Meadows, Victoria (38º10’56.45’’S, 145º19’34.10’’E). Soils were collected from sites that: (1) had been amended for three seasons with the corresponding carbon amendments listed below and used to grow a rotation of vegetable crops (Section 6.6), (‘*Amended*’ treatment), (2) had never been amended with carbon inputs, but was used to grow the same rotation of vegetable crops as the *Amended* treatment (‘*Non-Amended’* treatment), and (3) had never been amended with carbon inputs and had no history of vegetable production (the site was an abandoned pasture near a roadside), (‘*Virgin*’ treatment). All collection sites were within 20 m of each other.

Treatments: Carbon amendments

The following carbon amendments were applied at commercial rates to the three soil history treatments: vetch, 5 t/ha; compost, 10 t/ha; and biochar (parent material hardwood chips), 10 t/ha. Controls consisted of untreated soils and sterilised soils (double autoclaved).

Amended soils were placed into sterile tissue culture vials (250 mL) and 30 sclerotes (laboratory-grown) of *S. minor* buried into the top 5 mm of the amended soils. The tissue culture vials were sealed and incubated at 20ºC in the dark.

Sclerote Viability

After various incubation periods, sclerotia were retrieved from soils using a wet sieving technique (Villalta et al., 2010). Recovered sclerotia were surface sterilised (in a mixture of ethanol and sodium hypochlorite) and plated individually onto PDA drop plates (as per Villalta et al., 2010). Two weeks following plating, sclerotia were assessed for their viability by examining for hyphal growth and new sclerotia production.

Design

The trial was conducted as a randomised factorial design with four blocks. Treatments were: soil history (three levels: amended, non-amended and virgin) and carbon amendments (six levels: vetch, compost, biochar, untreated, and untreated). There was one vial containing 30 sclerotia per treatment per block per sampling period.

5.6.3 Results

1-week after incubation

After 1 week of incubation, there was a significant interaction between soil history and amendment treatments on the viability of sclerotia. In this interaction, vetch-amended soils reduced the viability of sclerotia by nearly 35% compared with untreated soil. However, this reduction only occurred in soil previously amended with vetch (ie the 'amended' treatment), and not in soils with no history of amendment (ie the 'unamended' treatment) or in virgin soil (Figure 5.11). Individually, the main treatments of soil history and amendment did not significantly affect the viability of sclerotia.

1-month after incubation

After 1 month of incubation, the viability of sclerotia in vetch- and biochar-amended soils had fallen by 40% and 20%, respectively, compared with untreated soil (Figure 5.12). This effect occurred across all soil history treatments. There was no significant effect of soil history on viability of sclerotia. The interaction between soil history and amendment treatments was no longer significant.

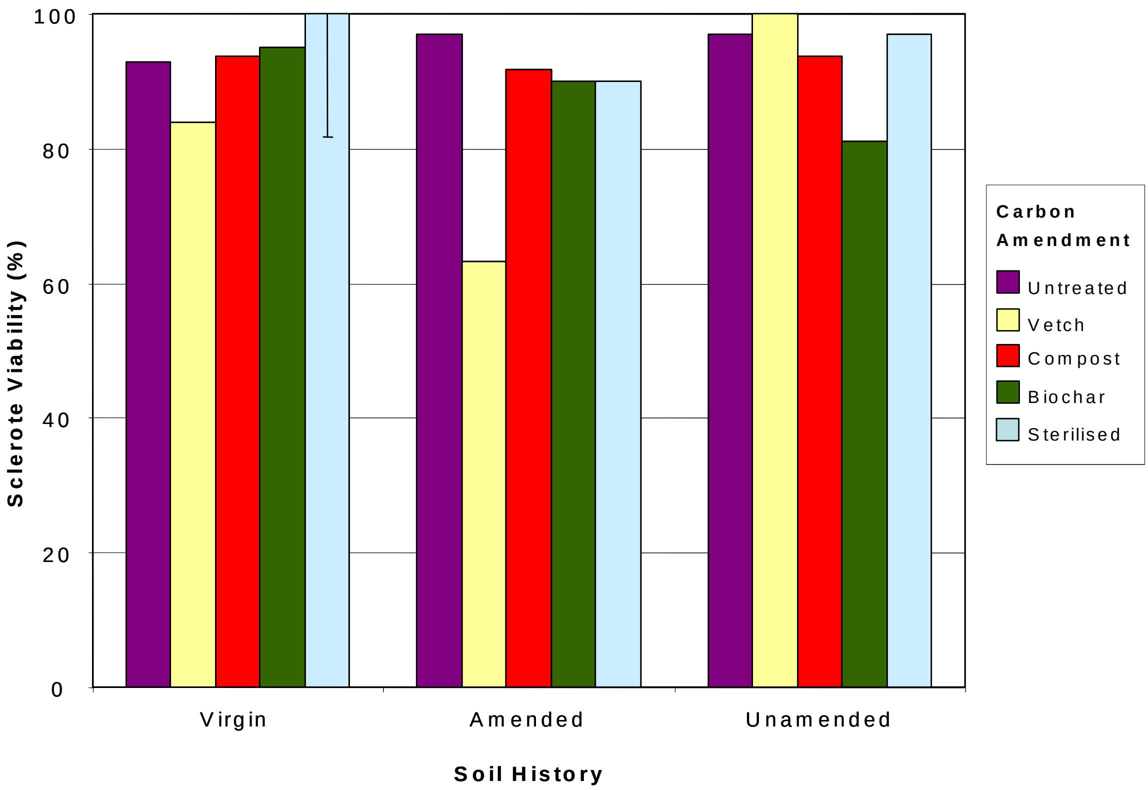


Figure 5.11 Viability of sclerotia of *Sclerotinia minor* after 1-wk buried in soils with a history or no-history of carbon amendment, and then treated again with various carbon amendments. There was a significant interaction between soil history and carbon amendment treatments. The error bar is the least significant difference where p = 0.05.

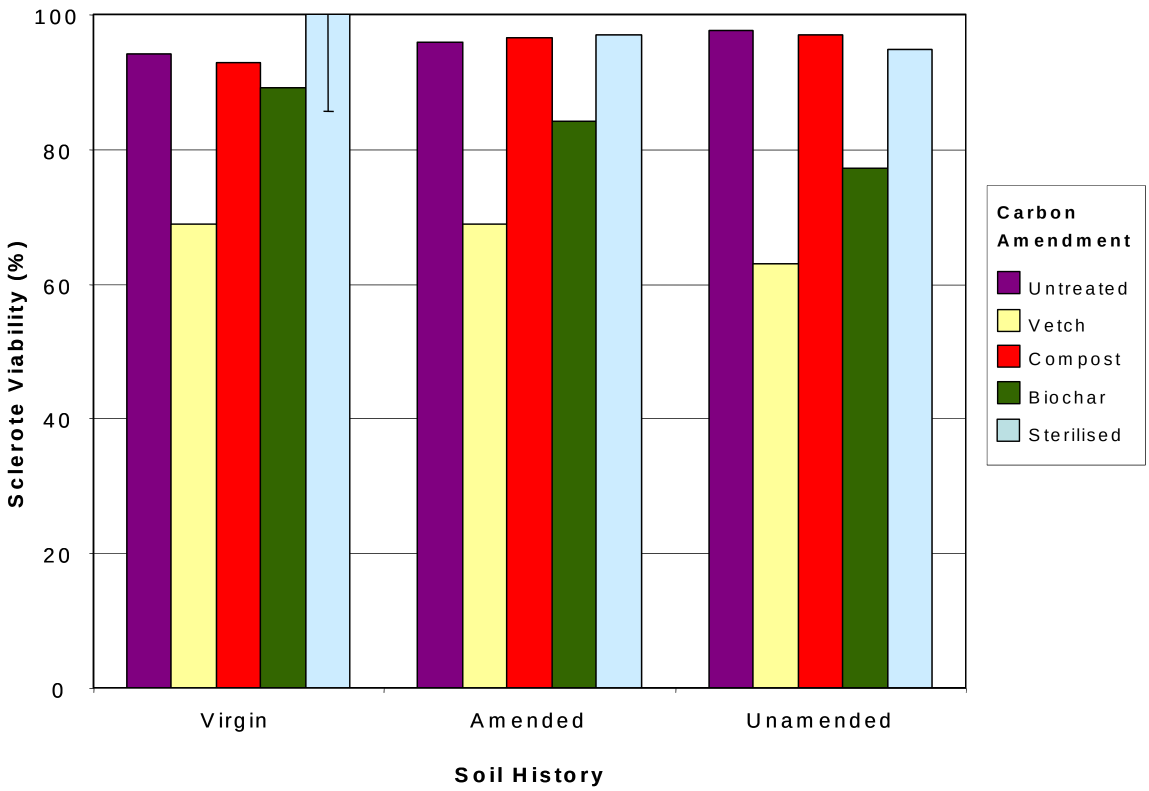


Figure 5.12 Viability of sclerotia of *Sclerotinia minor* after 1-month buried in soils with a history or no-history of carbon amendment, and then treated again with various carbon amendments. The error bar is the least significant difference where p = 0.05.

5.6.4 Discussion

Of the carbon inputs investigated, amending soils with vetch showed the greatest potential for degrading sclerotia of *S. minor*. Vetch was higher in labile carbon than the other amendments used in this trial, and therefore it was expected to stimulate soil microbial activity. This may have contributed to enhanced biological degradation of sclerotia. Additionally, vetch can produce a range of allelochemicals (eg cyanamides) that may directly effect degradation of sclerotia.

Degradation of sclerotia by vetch occurred faster in soils that had a history (3 seasons) of being amended with vetch than in soils that had not. One possible explanation for this is that long-term amendment of soil with vetch may stimulate microbial populations that readily utilise it as a carbon source and/or tolerate the allelochemicals it produces. Components of these microbial populations may also have the capacity to degrade sclerotia. Re-fueling the soils with a further vetch amendment would allow these specific populations to rapidly build up again, thereby degrading sclerotia faster than in soils with no history of vetch amendment.

After one month of incubation, soils amended with biochar also showed evidence of increased degradation of sclerotia than untreated soils. In contrast to vetch, however, degradation of sclerotia by biochar amendments was no more rapid in soils with a history of amendment.

5.7 Conclusions

Laboratory and glasshouse trials conducted under controlled conditions showed:

- Adding carbon amendments to soil either decreased or increased inoculum of soil-borne pathogens. The outcome depended on the form and type of pathogen (eg sclerotia or hyphae, saprophytic ability) and carbon amendment added to soil (eg labile carbon content). For example, amending soils with vetch or biochar enhanced degradation of sclerotia of *S. minor* in soil. In contrast, adding compost, biochar, lignite and humate to soil increased concentrations of *R. solani*. We hypothesise that the stronger the saprophytic ability of a pathogen is, the more likely that its inoculum will increase following addition of carbon amendments into soil.

- Irrespective of the effect on inoculum, adding carbon amendments to soil had the capacity to decrease expression of soil-borne diseases in vegetable crops. For example, adding humate and compost to soil reduced the incidence of damping-off in radish by up to 60%, even though this treatment increased the concentration of the pathogen in the soil. In these cases, disease suppression was probably due to an increase in specific groups of soil microflora that interfere with pathogenesis through antagonism.

- Amending soils with carbon inputs affected clubroot expression in brassicas by modifying soil pH. In particular, amendments that lowered pH, such as lignite, increased expression of clubroot. Such amendments may need reformulation or co-application with lime in soils where clubroot is a problem.

- There was a positive relationship between increased labile carbon and biological activity in soil. Furthermore, increased biological activity was associated with increased disease suppression of damping-off in radish and clubroot in broccoli.

The impact of carbon amendments on soil-borne pathogens and disease involves complex biological and chemical interactions. Vegetable growers need greater certainty of effects of organic amendments before they will widely adopt them for disease mitigation purposes. This will require greater knowledge of: (1) the mechanisms that drive disease suppression by organic amendments; and (2) the impact of specific amendments on specific crop/pathogen systems under specific environments and soil types. Further research is needed on the changes in soil biota and the chemical shifts in soil following amendment with carbon inputs, and new molecular technologies are now available to make this next step (Mele, 2010). This will require further research investment by industry, but ultimately the benefits will include: increased sustainability of production, more reliable disease control with reduced pesticide inputs, and increased carbon sequestration into soils.

6 Field trials in southern Australia

Field trials in southern Australia evaluating the impact of standard grower practices on soil health, crop productivity and grower profit

6.1 Introduction

Pesticide withdrawals and increased consumer demand for produce with minimal synthetic inputs are placing pressure on growers to adopt alternatives for managing soils and soil-borne pests (e.g. diseases, weeds) in vegetable crops. In response to a scoping study on soil health (VG06090), HAL and the vegetable industry requested that this project identify the cost benefits that could be gained by investment in soil health research. In particular, what benefits would industry gain by using more sustainable cropping practices for yield and disease control, and what benefits/losses could be derived from more efficient fertiliser use and reduced water inputs.

In response, six short term trials were conducted at vegetable farms in Victoria and Tasmania to determine the impact of common farm practices used throughout the National vegetable industry on soil health. These trials also assessed which soil health indicators best measured the physical, chemical and biological changes that occur with the different practices. Victorian trials examined the effects of fumigants, fungicides, fertilizers and composts on crop yield and soil characteristics. A Tasmanian trial examined the effects of green waste and paper sludge organic amendments on production and soil properties.

Two long term trials were also carried out to evaluate the effects of more sustainable cropping practices using different organic amendments and rotation crops on crop productivity and soil health. The trials were conducted at separate locations in Victoria, at Boneo on the Mornington Peninsula and Devon Meadows approximately 50 km South East of Melbourne. Organic amendment treatments were repeatedly applied to the same plots over a three year period to determine which amendment could best contribute to yields and building organic carbon. Changes in soil carbon, organic matter, biological activity, crop yield and disease were monitored over the three year period (see also chapter 7). Numerous soil physical, biological and chemical parameters were also recorded.

Good soil health is largely driven by the amount of carbon in the soil (Janvier *et al.* 2007), which provides both the food for soil organisms (good and bad) and helps build the good soil structure required for root growth and water storage. Cropping practices within the vegetable industry, especially tillage tend to reduce soil carbon levels, and the greater the intensity of cultivation, the greater the loss. Within raised bed vegetable production systems in Australia, soils are typically cultivated many times prior to planting. As a consequence, soil organic matter levels are typically low; often around 1-2%. In an effort to build soil organic matter and soil health, vegetable growers may incorporate green manure crops, composts, animal manures or other organic inputs into soils. This chapter reports on short- and long-term field trials conducted in the vegetable industry aimed at characterising the effects of organic and synthetic cropping inputs on soil health, crop disease, yields and profitability.

6.2 General Methods

6.2.1 Trial locations

Six short term trials, at vegetable farms in Victoria and Tasmania, and two long term trials in Victoria were conducted to determine the impact of common farm practices used throughout the National vegetable industry on soil health (Table 6.1).

Table 6.1 Field trial details

Trial	Location	Trial type	Crop	Transplant	Harvest
ST1	Boneo, Vic	Short term	Broccoli cv. Ironman	08/07/08	01/10/09
ST2	Boneo, Vic	Short term	Broccoli cv. Viper	11/03/08	20/05/08
ST3	Boneo, Vic	Short term	Broccoli cv. Belstar	26/03/09	22/06/09
ST4	Boneo, Vic	Short term	Broccoli cv. Belstar	18/12/09	16/02/10
ST5	Cambridge, Tasmania	Short term	Lettuce, Red Oak	12/08/08	13/11/08
LTY1	Boneo, Vic	Long term	Broccoli cv. Ironman	08/07/08	01/10/08
LTY2	Boneo, Vic	Long term	Broccoli cv. Belstar	30/03/09	01/07/09
LTY3	Boneo, Vic	Long term	Broccoli cv. Belstar	22/12/09	22/02/10
PS1	Devon meadows, Vic	Long term	Lettuce	30/06/08	02/09/08
PS2	Devon meadows, Vic	Long term	Endive	09/12/08	26/01/09
PS3	Devon meadows, Vic	Long term	Leek	03/03/09	24/08/09
PS4	Devon meadows, Vic	Long term	Parsnip	16/11/09	26/03/10

6.2.2 Sample collection

At each site, soil samples from treated plots were collected from the 0 to 15 cm layer of soil by pooling 10 to 20 cores using a soil corer. The samples were collected from 3 to 6 replicate plots for each treatment times depending on the site. Samples were sent to DPI, Knoxfield for processing where they were stored at 4°C until assessment.

6.2.3 Soil chemistry measurements

Soil testing was carried out by the Department of Primary Industries, Werribee Victoria for the properties detailed in Table 6.2 according to standards methods.

Table 6.2 Soil chemical measurements

Organic resources	Total Carbon/Nitrogen (Leco)	Carbon, Nitrogen and organic matter
pH and EC	pH and Conductivity	EC pH($CaCl_2$) pH(water)
Exchangeable cations	Ammonium acetate cations (with prewash)	Calcium, Calcium as % Magnesium, Magnesium as % Ca:Mg Potassium Potassium as % Sodium Sodium as % Sum of four cations Total soluble salts
Plant available nutrients (soil fertility)	Available Nitrogen Available Phosphorus Available Potassium Available Sulfur DTPA extractable trace elements	Ammonium-N Nitrate-N P (Olsen) Potassium Sulfur Copper Iron Manganese Zinc

6.2.4 Soil biological properties

Nematodes

Nematodes were measured by Biological Crop Protection (Qld) and Agri Science Queensland, Indooroopilly, Department of Employment, Economic Development and Innovation, according to the methods of Pattison (2009). Indices of nematode community composition were determined for nematodes detected in soil. Nematode diversity was calculated using the Shannon Wiener index (H') (Yeates and Bongers 1999). The percentage of nematode in different feeding groups (bacterial feeder, fungal feeders, plant parasitic and predator nematodes) were calculated as well as the B/F ratio (=B/(B+F) where B is the proportion of bacteriovores and F is the proportion of fungivores).

The basal, structure and enrichment conditions of the soil foodweb and the decomposition channel of nutrients were examined (Ferris et al 2001). Enrichment index (EI) is a measure of the resources available in the soil food web and the response of primary decomposers to those resources, Structure index (SI) is a measure of the number of trophic layers in the soil food web. Channel index indicates the decomposition channel of nutrients with low and high values suggesting dominant bacterial decomposition and fungal-dominated decomposer nematode communities.

Soil respiration

Soils were air dried at 40^{o}C for 48 hours. Soil (30 g) was lightly pack (1 g/cm/) in incubation containers (40 mm PVC tube, 3 cm high, mesh bottom, aperture 0.06mm). Samples were wet up to 55% water holding capacity (± 5%) by placing them in a 'wet up' bath of distilled water. Actual water content was determined gravimetrically. Wet up samples were then placed in an incubation chamber (1 litre air tight jar). A water reservoir (30 ml of distilled water) was placed in the incubation chamber to maintain humidity. Chambers were incubated in controlled temperature room at 25°C in darkness. CO_2 measurements were taken at 4 and 14 days using a Servomex 1450 CO_2 analyser.

Labile carbon
Soil labile carbon was determined on a 3 g sample of air dried soil (40 °C for 48 hours), sieved to 1mm, according to the potassium permanganate method of Blair et al (1995).

Fluoresein diacetate activity (FDA)
Soil microbial activity was measured using the method described by Schnurer and Rosswall (1982) based on the hydrolysis of fluorescein diacetate. This assay measures the presence of universal enzymes (e.g. lipases, proteases, etc) of biological origin and function in soil. Each analysis was performed on 5 g of air dried soil.

6.2.5 Clubroot disease assessment

Clubroot symptoms were assessed at harvest in broccoli trials according to the severity of root galling (on 5 to 10 plants per replicate) from 4 replicates of each treatment (5 plants in LTY1 and ST1 (Nitrogen trial), 10 plants in LTY2 and LTY3). A 0-3 rating scale was used where 0 = no galls, 1 = 1 - 10%, 2 = 11 - 50% and 3 = > 50% roots galled (Donald et al. 2004).

6.2.6 Yield assessment

Yield was assessed on a 5 m section of each experimental plot for all Broccoli trials. Marketable heads were harvested upon maturity on up to three occasions (cuts) per crop. There were no differences in the trends of treatments on yield at the different cuts. Therefore yield was expressed as the cumulative fresh weight of heads for all cuts.

6.2.7 Profitability calculations

The effects of treatments on the profitability of broccoli production were calculated for trials ST2, ST3, ST4 and the long term trial (LTY1, LTY2, LTY3). All treatment costs were similar for all plots up to the base fertilizer application. The relative treatment costs used in profitability calculations reflected the additional treatment costs incurred post base fertilizer application. Profit relative to standard grower practice was calculated using yield and at a market price of $1.80/kg less the treatment costs above the standard grower practice. The costs of treatments used is shown in appendix 6.1

6.3 Short term trials – Boneo, Vic

6.3.1 Methods

These trials were conducted over a three year period (2008-2010) on a commercial vegetable farm with sandy loam soil at Boneo on the Mornington Peninsula, Victoria. There were four short term trials (ST1, ST2, ST3 and ST4) conducted in autumn 2008, autumn 2009 and summer 2010.

All trials were sown with broccoli transplants (cv Ironman, Viper and Belstar) according to the season (Table 6.1). All broccoli plantings were approximately 30,000 plants/ha and experimental plots were 17.2 m^2 in area (10.62 m long x 1.62 m wide). In all short term trials, treatments were replicated four times in a randomised block design.

Short Term Trial 1 (STI) - Effect of Nitrogen Fertilizers on Crop Yield and Soil Health

AIM: The aim of the trial was to evaluate whether different forms of nitrogen fertilizers used at commercial rates, which are more beneficial to the environment and soil health, could give similar or greater yields than the existing commercial use of Nitrobor, a combination of calcium nitrate and boron.

Calcium nitrate is very soluble and thus may cause nitrate flow problems for the sandy soils in the region. Preliminary measurements in this study showed that a high proportion of this product (as much as 50%) may flow off the tops of the beds during irrigation. Perlka®, Alzon® and Urea are less soluble in soil and each contains mechanisms to allow for slow release of nitrate into soil for the crop to utilize. Alzon® contained inhibitors to prevent nitrification early in a crop, Perlka® provides toxic by-products to control weeds and pests and then releases nitrate slowly and urea relies on soil nitrifying bacteria to release nitrate from the ammonia. These products were not considered to create nitrate flow issues. They were also considered to have potential for improving crop yields due to the slow release fertilizer effect. This trial consequently tested the effects of these different forms of nitrogen fertilizer on crop yield, disease and soil properties.

The treatments applied in trial ST1 are shown in Table 6.3.

Table 6.3 Nitrogen trial treatments used in short term trial ST1 (2008)

Treatment	Nitrogen form	% Nitrogen	Rate (kg/ha)
$CaNO_3$ (banded)	Nitrate	15.5	250
Urea	Urea	46.0	1000
Alzon®	Urea + nitrification inhibitor	46.0	500
Perlka®	Calcium cyanamide	19.8	500

All plots also received a budding application of 220-247kg/ha $CaNO_3$ which is the standard grower practice.

Short Term Trials 2, 3 and 4 (ST2, ST3, ST4) - Effect of Crop Management Practices on Crop Yields, Grower Profit and Soil Health

AIM: To determine the effect on soil health, crop yields and profit of sustainable practices (biofumigant and organic amendments) compared to the standard grower practices (liming, fungicides, fumigants) used for cropping broccoli in the region.

The treatments used were fertilizer and disease control practices commonly used for control of the major soilborne disease of broccoli in the region, ie. clubroot caused by *Plasmodiophora brassicae* (Table 6.4). The grower standard treatment included application of 2 t of hot lime (CaO) to the soil surface 14 days before transplanting, 125 kg/ha of Nitrabor® ($CaNO_3$ + B) applied to the soil surface at transplanting and then application of 300 kg/ha of Rustica Gold® base fertilizer side dressed during the week after transplanting. In the first of these trials (ST2), composted chicken manure was applied at 5.25 t/ha to the surface of beds 4 days prior to transplanting to all treatments. In the second two trials (ST3 and ST4) the surface chicken manure application to all plots was omitted.

Table 6.4 Treatments and rates of products used in short term trials (ST2, ST3, ST4) at Boneo, Victoria (2008-2010)

Treatment*	Products applied in addition to Rustica Gold®	Treatment rates		
		ST2	ST3	ST4
Untreated	None	-	-	-
Standard practice	$CaNO_3$	197 kg/ha	250 kg/ha	220 kg/ha
$CaNO_{3\ (b)}$ (banded) and side dressed	$CaNO_3$	-	125 kg/ha + 125 kg/ha	110kg/ha + 110 kg/ha
$CaNO_{3\ (b)}$ + Fluazinam	$CaNO_3$ Fluazinam	-	250 kg/ha 2.05 L/ha	220 kg/ha 2.05 L/ha
Lime	Lime	2 t/ha	2 t/ha	2 t/ha
Fluazinam	Fluazinam	2 L/ha	2.05 L/ha	2.05 L/ha
Lime + $CaNO_{3\ (b)}$	Lime $CaNO_3$	2 t/ha 250 kg/ha	2 t/ha 247 kg/ha	2 t/ha 220 kg/ha
Chicken manure	Composted chicken manure	-	16.5 t/ha =5 tC/ha	16.5t/ha =5 tC/ha
Lime Fluazinam	Lime Shirlan®	-	2 t/ha 2.05 L/ha	2 t/ha 2.05 L/ha
Lime $CaNO_{3\ (b)}$ Fluazinam	Lime $CaNO_3$ Fluazinam	2 L/ha 250 kg/ha 2.05 L/ha	2 t/ha 247 kg/ha 2.05 L/ha	2 t/ha 220 kg/ha 2.05 L/ha
Metham sodium 425	Metham sodium	425 L/ha	425 L/ha	425 L/ha
Metham sodium 850	Metham sodium	800 L/ha	850 L/ha	850 L/ha
Alzon®	Alzon® (NH_4 + nitrification inhibitor)	400 kg/ha	400 kg/ha	400 kg/ha
Compost	Composted green waste	43 t/ha	26.5 t/ha =5 tC/ha	26.5 t/ha =5 tC/ha
Fumafert®	Fumafert® (Mustard meal)	2 t/ha	2 t/ha	2 t/ha
Voom®	Voom® (Mustard oil)	70 mL/m^2	50 mL/m^2	25 mL/m^2
Perlka®	Perlka® (Ca cyanamide)	1000 kg/ha	750 kg/ha	750 kg/ha
Fumafert® and Lime	Fumafert® Lime	2 t/ha 2 t/ha	-	-
Voom® and Lime	Voom® Lime	5% 2 t/ha	-	-

* All plots received 220-247 kg/ha of $CaNO_3$ at budding as per standard grower practice.

6.3.2 Results and Discussion

In this section, a subset of key measurements recorded in the trials will be presented and discussed. The full results for all field trials are presented in Appendices 6.1-6.46`.

Effect of ammonium and nitrate fertilizers on crop yield (STI) - Yield effects

In the nitrogen fertilizer trial (ST1), there were no significant effects on either broccoli yield or clubroot severity at harvest (Table 6.5) showing that the alternative ammonium based fertilizers were similar to the standard grower practice. This result was extremely positive as it indicates that treatments which are expected to lead to healthier soils, have potential to replace the negative impact of $CaNO_3$ on the environment. All the ammonium treatments increased yields 5 - 10% above $CaNO_3$ although this was not significant at P=0.05.

Table 6.5 Broccoli yields per plot (17.2 m^2) and clubroot disease severity in the nitrogen fertilizer trial (Trial ST1).

Treatment	Yield (kg/ plot)	Clubroot severity (0-3 scale)
Urea	7.23	0.133
Alzon®	7.04	0.097
Perlka®	7.40	0.142
$CaNO_3$	6.63	0.097
LSD (P=0.05)	n.s	n.s

n.s - not statistically significant (5%)

Effect of crop management trials on crop productivity, profit and soil health (ST2, ST3 and ST4) – Yield effects

In the short term trials conducted over three consecutive years (ST2, ST3 and ST4), metham sodium, at both 425 and 850 L/Ha, and Alzon® resulted in an average yield increase of approximately 15% compared to the standard grower practice (Figure 6.1). These treatments resulted in yield increases in all years, but this varied between 10 to 20%. Alzon® had greater effect in the summer crop in 2010 (Trial ST4) (Figure 6.2). In 2008, the hot lime soil treatment applied and incorporated immediately 10 days before cropping followed by split band application of $CaNO_3$ was the most effective treatment (Figure 6.2).

Fumafert®, compost and chicken manure also resulted in increased yield on average but to a lesser extent (7-10% increase relative to standard grower practice) and did not increase yields consistently in all trials (Figure 6.2). These treatments had a greater influence on yield for the summer grown crop.

$CaNO_3$ applied alone and $CaNO_3$ + Fluazinam resulted in mean yield decreases of more than 50% relative to standard practice when averaged across the three trials. All other treatments that included the fungicide fluazinam resulted in yield decreases relative to standard practice which may be due to phytotoxicity. Although fluazinam provides excellent control of clubroot, previous studies have shown that it can delay crop maturity and reduce crop yields when clubroot is not present.

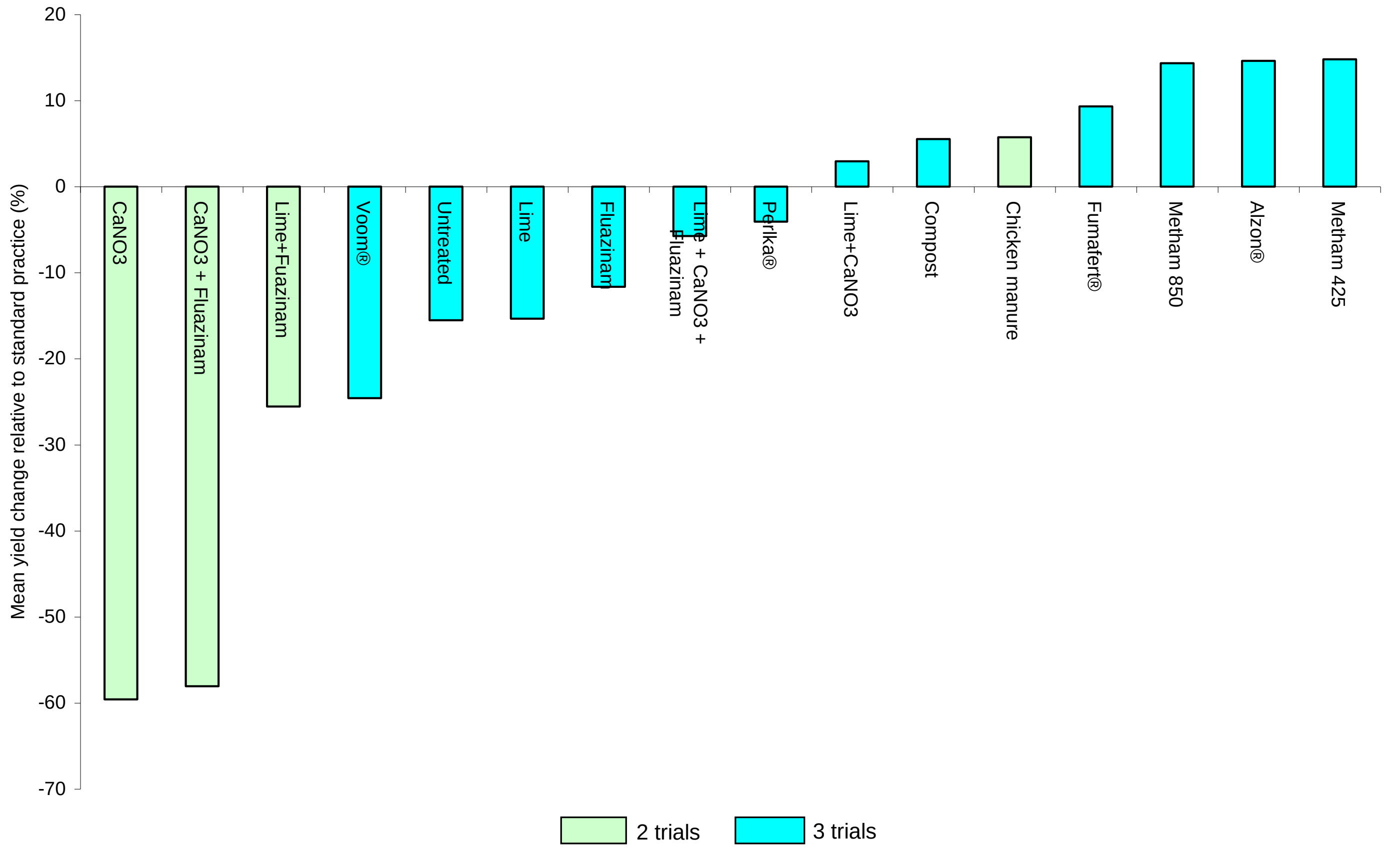
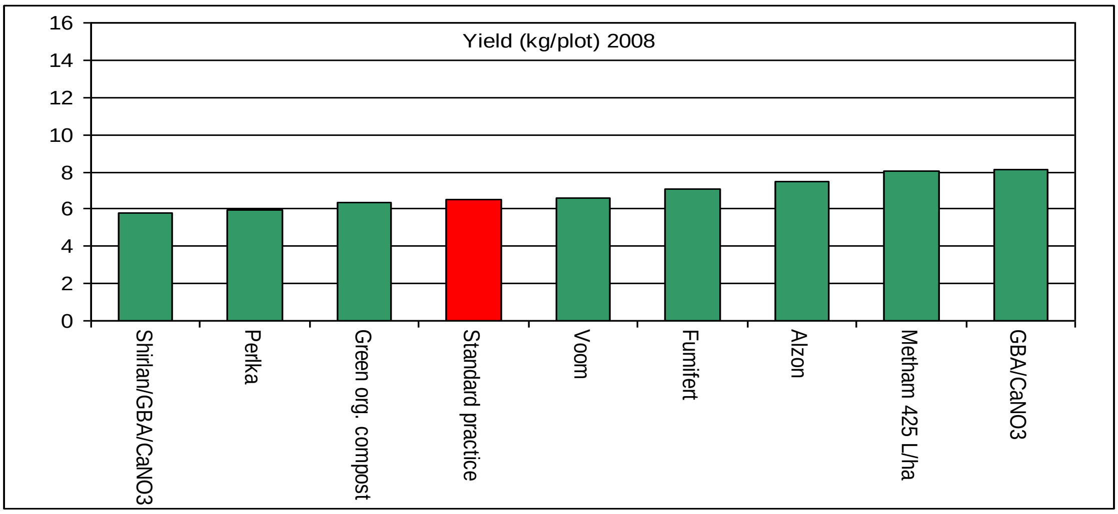
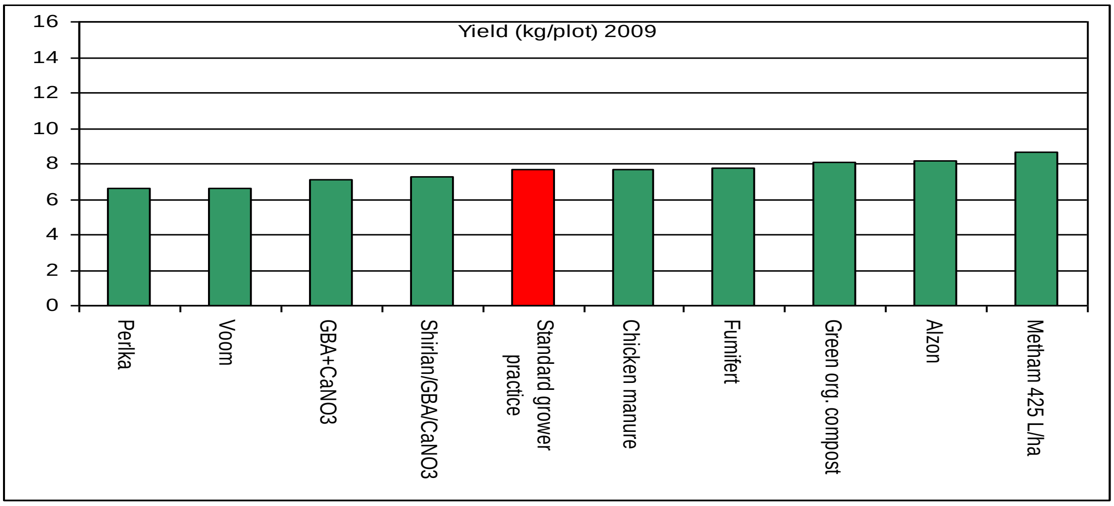


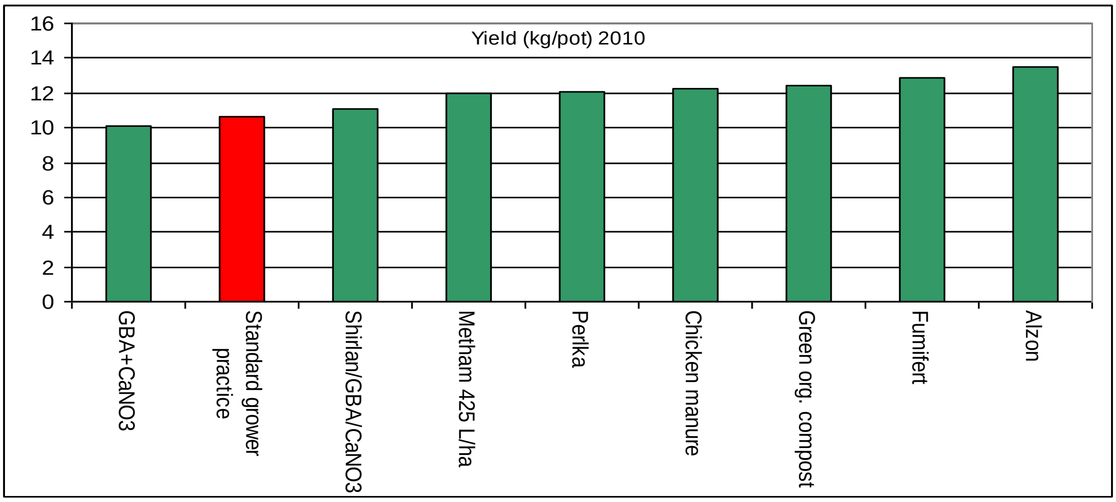
Figure 6.1 Mean yield change (%) relative to standard practice for treatments in the short term trials (ST2, ST3 and ST4). The mean yield in the standard practice treatment was 8.55 kg/5 m (10.56 t/ha)



Autumn 2008



Autumn 2009



Summer 2010

Figure 6.2 Effect of some key organic and inorganic amendments applied to soil on yield (kg/5m) and profit in a loamy sand at Boneo in Victoria in autumn 2008 (ST2) and 2009 (ST3), and summer 2010 (ST4).

Profitability

Changes in profitability of experimental treatments relative to the standard practice treatment were calculated using the DPI Gross Margin Model (Figure 6.3). Gross margin calculations did not include costs for pest, disease and weed control or irrigation or harvesting and processing costs as these were assumed to be the same for all treatments. The unit costs for treatments are shown in Appendix 6.1.

Figure 6.3 Example of the DPI Gross Margin model spreadsheet.

Profitability relative to standard practice was improved by metham sodium treatments and Alzon® in all trials by $800 – $6000/ha (Table 6.7, Figure 6.4, Figure 6.5, Figure 6.6). Fumigation usually gives a yield response in these sandy soils and this result was not unexpected, however the large response to Alzon® was unexpected. This result appears to indicate that this product, which contains inhibitors to slow down nitrification, is could be very beneficial to crop productivity and increased grower profits in the sandy soils in southern Victoria.

The organic treatments (Fumafert®, compost and chicken manure) tended to provide profit return when applied before the summer crops, but not before the autumn crops. This appears to indicate that the treatments had a greater fertilizer effect when applied at higher soil temperatures or that the higher temperatures released some of the nutrients which may be tied to the organic products during the lower soil temperatures in autumn.

$CaNO_3$ + lime treatment resulted in a large increase in yield and profit in the initial trial in 2008 (ST2), but decreased profitability in the other two trials.

Table 6.6 Effect of treatments on the profitability of broccoli production in the short term Boneo trials.

Trial	Treatment	Treatment cost[1] $/Ha	Yield kg/ha	Income/ha @ $1.80/kg	Profitability relative to standard practice $/ha
ST2	Standard practice	524	8,076	14,537	0
	Lime + CaNO3	1,046	9,990	17,982	2,923
	Metham 425 L/ha	1,259	9,904	17,827	2,554
	Alzon	840	9,225	16,604	1,751
	Metham 850 L/ha + Lime	2,516	10,027	18,049	1,520
	Metham 850 L/ha	1,994	9,731	17,516	1,508
	Fumifert	2,024	8,866	15,960	-77
	Lime	882	8,002	14,404	-491
	Fluazinam	844	7,632	13,737	-1,120
	Rustica	360	7,348	13,226	-1,148
	Voom	2,024	8,175	14,715	-1,322
	Fumifert + Lime	2,546	8,373	15,071	-1,489
	Compost	2,511	7,891	14,204	-2,321
	Perlka	1,710	7,372	13,270	-2,453
	Fluazinam + Lime + CaNO3	1,366	7,113	12,803	-2,576
	Voom + Lime	2,546	7,199	12,959	-3,600
ST3	Standard practice	566	9,435	16,983	0
	Metham 425 L/ha	1,301	10,669	19,205	1,488
	Alzon	840	10,049	18,089	832
	Metham 850 L/ha	2,036	10,459	18,827	374
	CaNO3	568	9,558	17,204	220
	Chicken manure	1,110	9,515	17,127	-400
	Fluazinam	688	9,095	16,371	-734
	Compost	2,717	9,959	17,927	-1,206
	Fumafert	2,066	9,564	17,216	-1,267
	Fluazinam + Lime + CaNO3	1,418	8,941	16,093	-1,742
	Lime + CaNO3	1,090	8,755	15,760	-1,747
	Rustica	360	8,255	14,859	-1,917
	Fluazinam + Lime	1,210	8,582	15,448	-2,178
	Lime	882	8,255	14,859	-2,439
	Perlka	1,373	8,181	14,726	-3,063
	Fluazinam + CaNO3	896	7,882	14,188	-3,125
	Voom	1,637	8,193	14,748	-3,305
ST4	Standard practice	543	13,102	23,584	0
	Alzon	840	16,708	30,074	6,194
	Fumafert	2,043	15,911	28,641	3,557
	Metham 850 L/ha	2,014	15,757	28,363	3,309
	Chicken manure	1,088	15,158	27,285	3,156
	Perlka	1,373	14,911	26,840	2,427
	Metham 425 L/ha	1,278	14,806	26,651	2,332
	Compost	2,694	15,337	27,607	1,872
	Fluazinam + Lime + CaNO3	1,393	13,695	24,651	217
	Fluazinam + CaNO3	871	12,719	22,895	-1,017
	Lime + CaNO3	1,065	12,485	22,472	-1,633
	CaNO3	543	11,534	20,761	-2,823
	Rustica	360	10,256	18,460	-4,940
	Fluazinam	688	10,033	18,060	-5,669
	Fluazinam + Lime	1210	8,891	16,004	-8,247
	Lime	882	7,817	14,070	-9,853
	Voom	1079	5,421	9,758	-14,361

[1] Treatment costs do not include transport for materials used or application costs.

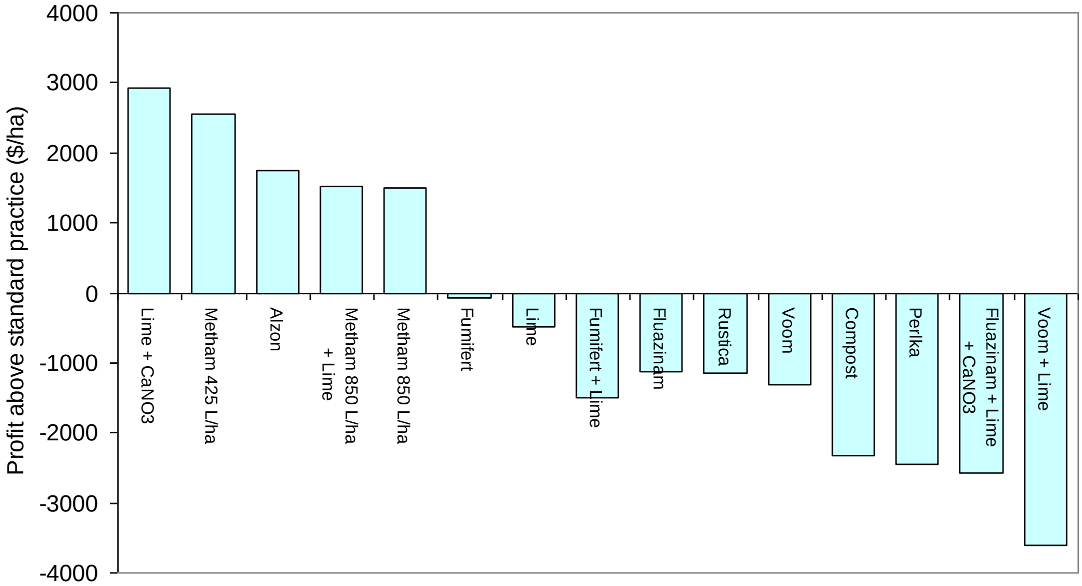


Figure 6.4 The effects of soil treatments on profitability of broccoli production relative to standard practice for short term trial in autumn 2008 (ST2).

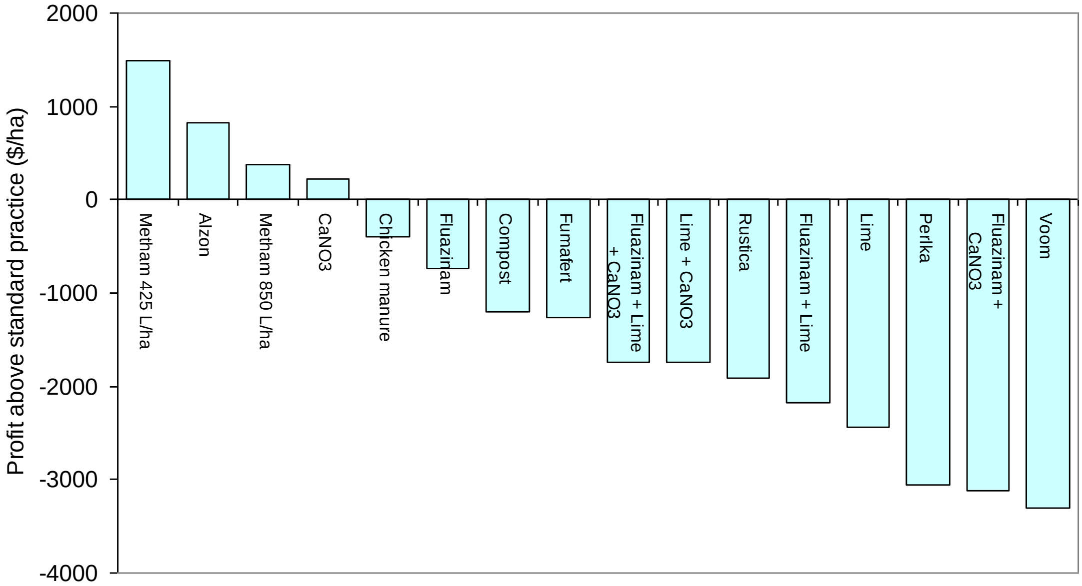


Figure 6.5 The effects of soil treatments on profitability of broccoli production relative to standard practice for short term trial in autumn 2009 (ST3).

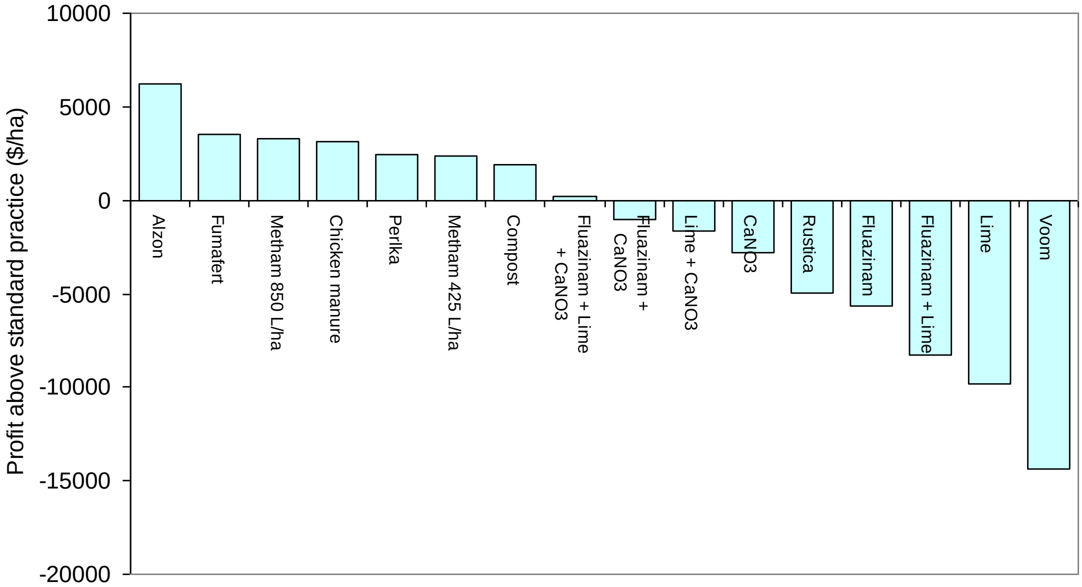


Figure 6.6 The effects of soil treatments on profitability of broccoli production relative to standard practice for short term trial in summer 2010 (ST4).

Soil pH

Significant pH differences between treatments occurred in two of the three field trials (in trial ST4 there were no significant pH differences between treatments at either transplanting or harvest). All soil pH (water) values were above the 7.5 recommended to minimise the impact of clubroot in brassica vegetables (Figure 6.7). Perlka®, lime and metham sodium treatments all increased pH at transplanting relative to standard practice while compost, Voom®, chicken manure and Alzon® all reduced pH. By harvest most of the pH differences had been reduced, except for lime which still showed a substantial increase. Treatments that reduce pH over the longer term may have implications for increased clubroot severity for brassica crops and may require co-application with lime.

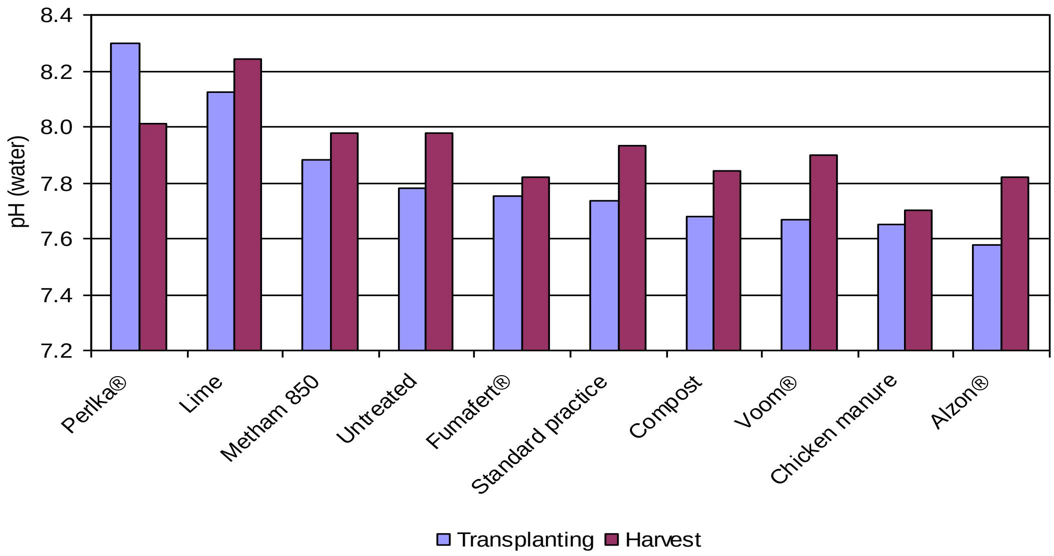


Figure 6.7 Mean effect of treatments on pH (water) over three* short term trials (ST2, ST3 and ST4) at transplanting and harvest (* pH was not recorded for treatments Standard practice in trial ST2 or for Perlka®, Fumafert® and Voom® in ST3).

Available phosphorous

Available phosphorous (Olsen) was not significantly different between any treatments in any of the field trials, but the baseline increased each year during the trials, showing that there has been a build up of phosphorus from base fertilizer application to plots over time. Available phosphorous in soil was generally greater than 90 mg/kg in all trials was in excess of the 27-63 mg/kg required for production of most vegetables (Prasad *et al.* 1988) (Figure 6.8). This indicates that phosphorus inputs have been excessive in this production system and could be decreased without affecting yield. This result also conforms to the benchmarking information which shows that over 71% of the sites benchmarked had excessive levels of phosphorus (Chapter 4). This is characteristic of many vegetable production regions around Australia (Chan *et al*. 2007).

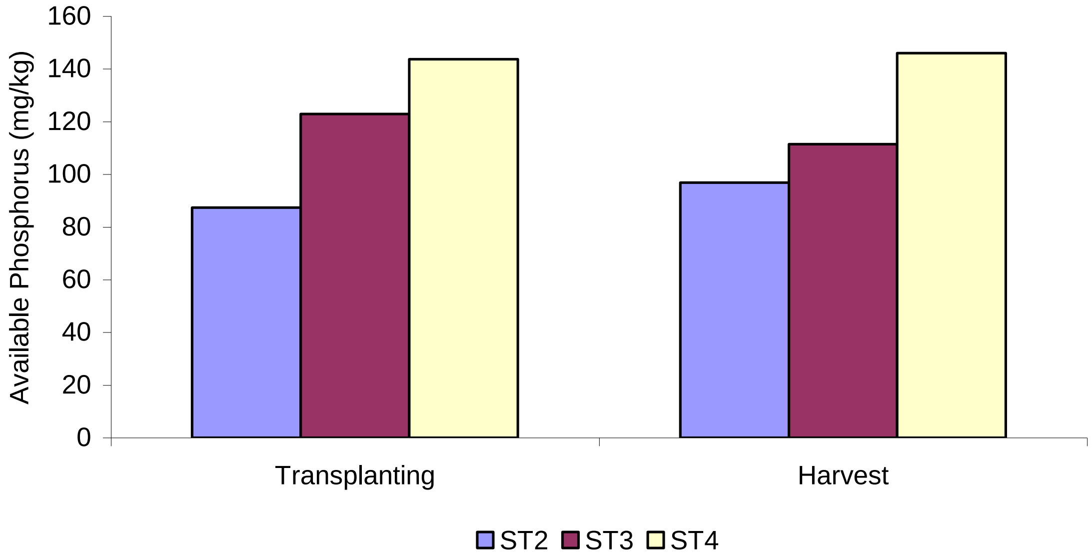


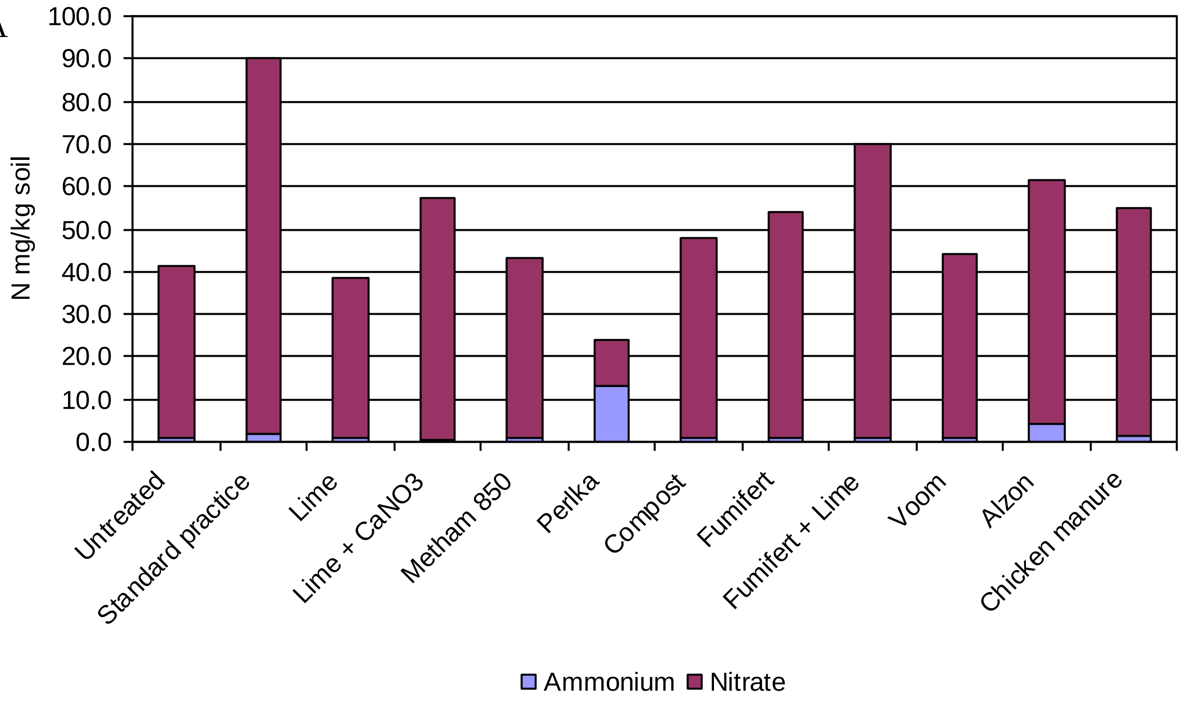
Figure 6.8 Average available phosphorus (Olsen) for the Boneo short term trials.

Available nitrogen

At transplanting, nitrate was the dominant form of available nitrogen for all treatments except Perlka® which had a high proportion of ammonium and lower nitrate (Figure 6.9). Alzon® also increased ammonium relative to standard practice. At harvest, metham, Perlka®, compost, Fumafert® and untreated soils all had higher ammonium levels than standard practice. In sandy soils, amendments with a higher proportion of ammonium nitrogen are less prone to losses through leaching than those with higher nitrate nitrogen.

Overall, treatment effects on available nitrogen (ammonium and nitrate) were not consistent between trials.

A



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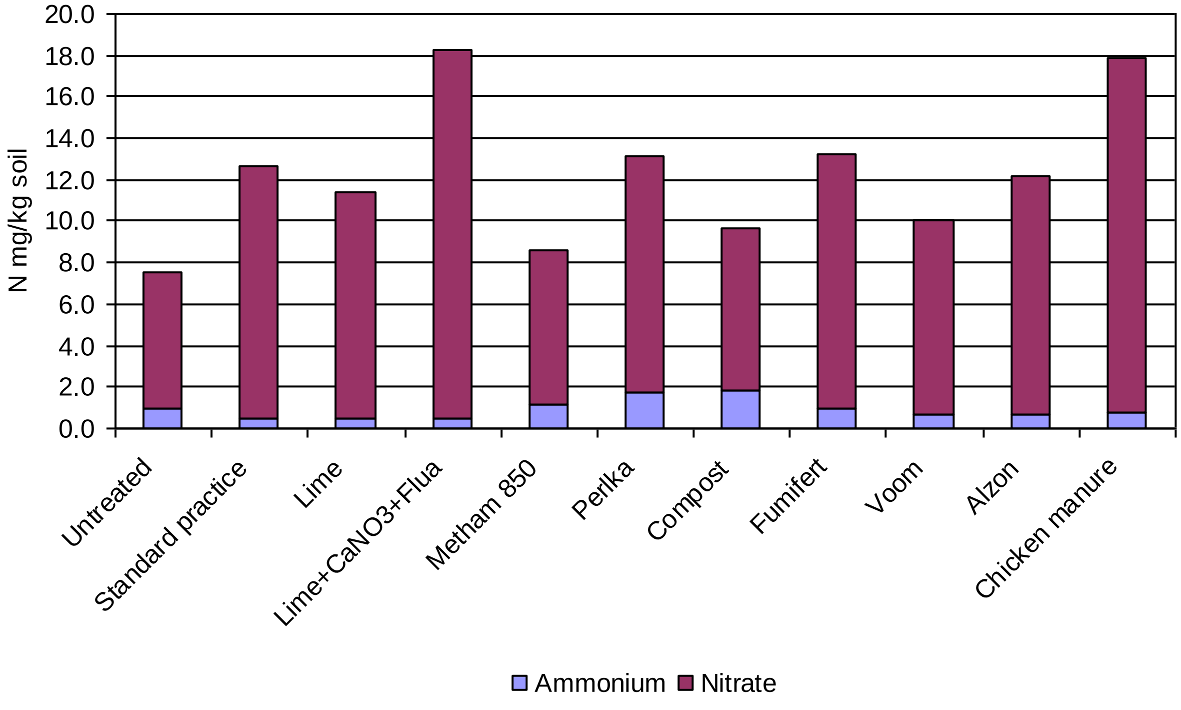


Figure 6.9 Mean available nitrogen at (A) transplanting and (B) harvest for the Boneo short term trials (ST2, ST3, ST4).

Total Nitrogen

The measurement of total nitrogen was problematic as many samples had values close to or below the limit of detection (0.05 g/100 g soil). In the first trial (ST2), total nitrogen was below the limit of detection for all samples at transplanting and most samples at harvest. Total nitrogen was higher in trial ST3 and ST4 for all treatments including untreated and standard practice. There were no significant differences in total nitrogen between treatments at transplanting for any of the trials.

At harvest in trial ST3, chicken manure and compost treatments had greater total nitrogen than standard practice (Figure 6.10). In trial ST4, compost had greater total nitrogen than standard practice while total nitrogen in the Alzon® and Voom® treatments was lower. This increase in total nitrogen at harvest would be expected due to the higher levels of organic nitrogen present in the amendments relative to synthetic nitrogen inputs.

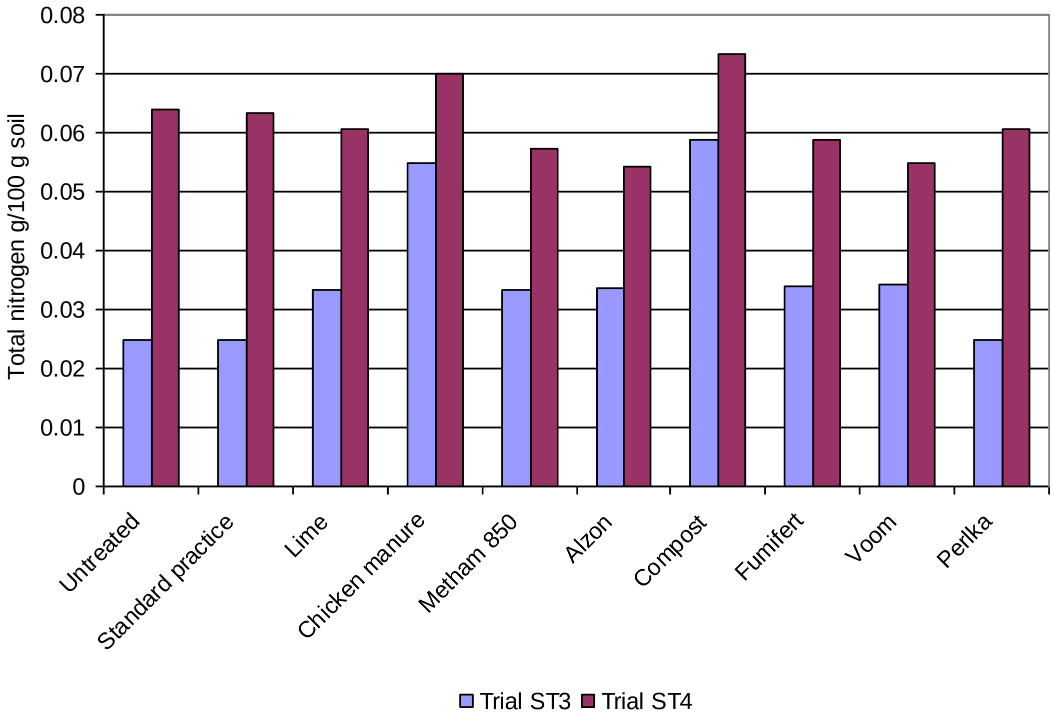


Figure 6.10 Total Nitrogen at harvest in trials ST3 and ST4

Total Carbon

Both compost and chicken manure treatments increased total carbon compared to the standard practice treatment at both transplanting and harvest when averaged across all trials (Figure 6.11). The Perlka treatment had slightly decreased total carbon at both sampling times. Organic matter is considered by many researchers to be a primary determinant of soil health (Janvier *et al.* 2007). Increased organic matter is beneficial to vegetable crop productivity by conserving soil moisture, improving biological activity (potentially increasing disease suppression and increasing nutrient cycling) and soil structure, all of which ultimately contribute to better soil health. A further evaluation of the impact of carbon changes in these trials at Boneo is discussed in Chapter 7.

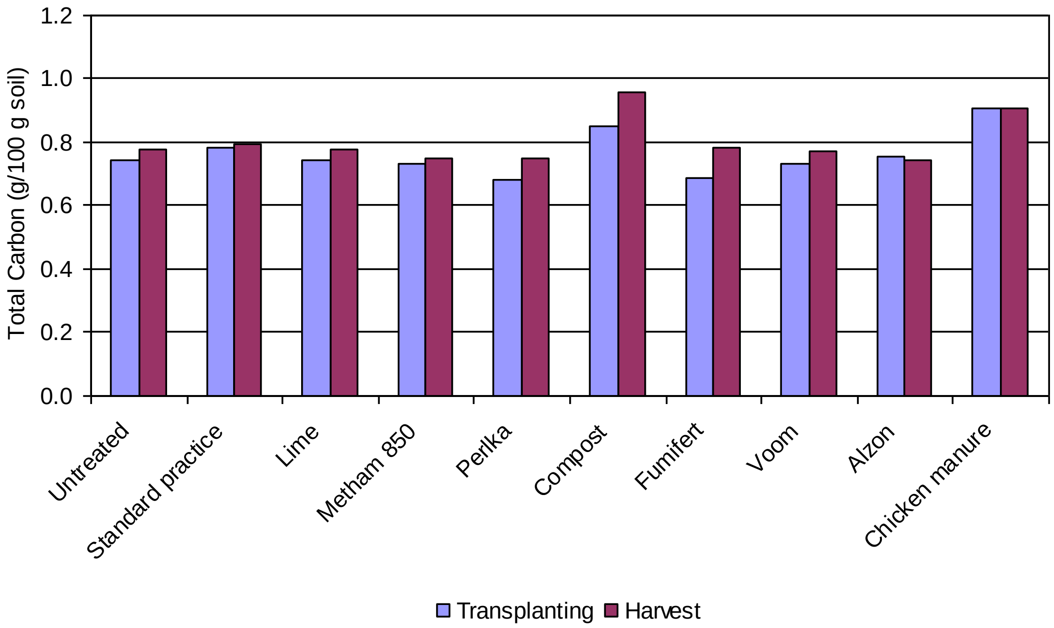


Figure 6.11 Mean total carbon in soil in the Boneo short term trials (ST2, ST3 and ST4)* at transplanting and at harvest. * chicken manure was only used in two trials (ST3 and ST4).

Cations

Available potassium varied between transplanting and harvest (means of 180 mg/kg and 88 mg/kg respectively) but generally there were no significant differences between treatments at either sampling time. The only exception was trial ST2 at transplanting, where Perlka® had approximately 20% lower available potassium than untreated while Alzon® had approximately 20% higher available potassium than untreated.

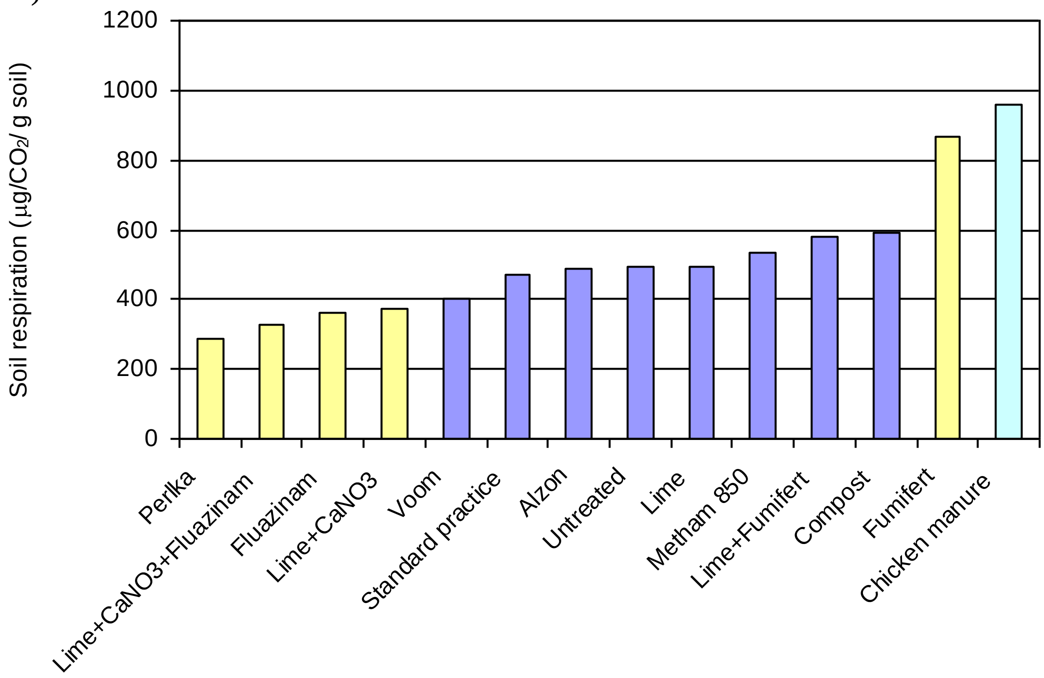
Biology

Measures of microbial activity

Increases in soil respiration were generally observed for treatments which included inputs of organic matter (compost and chicken manure) although these increases were not significant in all trials or for both crop stages (Figure 6.12). Voom® increased respiration in one trial and reduced it in another, relative to standard practice.

As anticipated a single application of a treatment to soils in trials had variable effects on soil biology and this suggests that changes in biology are transient during short term crop production in these sandy soils at this high input farm (Table 6.7).

A)



B)

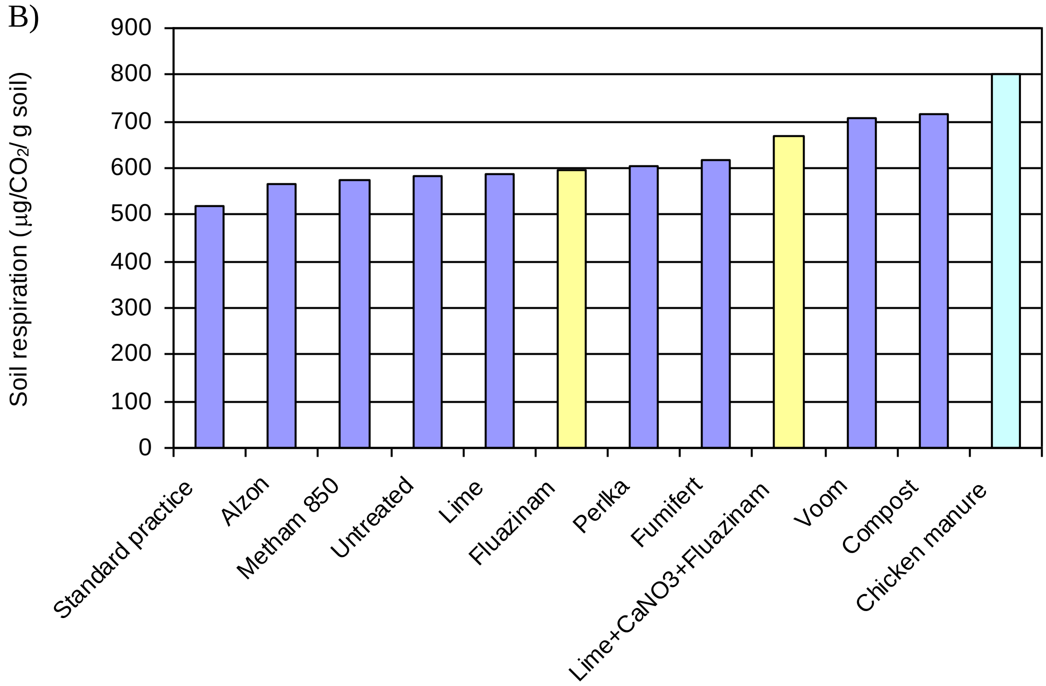


Figure 6.12 Mean soil respiration (14 days) for the three short term trials (ST2, ST3 and ST4) at A) transplanting and B) harvest. Yellow bars = 1 trial, light blue bar = mean of 2 trials, dark blue bars = mean of 3 trials

Table 6.7 Changes in soil biological activity relative to untreated (ST2) and standard practice treatments (ST3 and ST4)

Parameter	Trial ST2		Trial ST3		Trial ST4	
	Transplant	Harvest	Transplant	Harvest	Transplant	Harvest
Respiration 4 days	n.s	increased for compost and voom	n.s	increased for chicken manure	increased for compost	n.s
Respiration 14 days	n.s	n.s	n.s	increased for chicken manure, compost	increased for compost, reduced for voom	n.s
Labile Carbon	n.s	n.s	n.s	n.s	n.s	n.s
FDA activity	n.s	-	increased for chicken manure, Alzon®, Pelka®	increased for chicken manure, compost, Fumafert®, Voom®, Perlka®	n.s	n.s

n.s = no significant treatment effect at the 5% level

There were no significant differences in labile carbon observed in any of the trials at either transplanting or harvest.

Significant changes in soil microbial activity (FDA activity) were only observed in one trial (ST3). In this trial, chicken manure, Alzon® and Perlka® had increased FDA activity relative to standard practice at transplanting. The chicken manure, compost, Fumafert®, Voom® and Perlka® treatments had increased FDA activity at harvest. Increased microbial activity in soil may correlate with improved disease suppression and greater rates of nutrient release from organic matter.

Nematodes

The nematode variables SI (structure index) and CI (channel index), differed significantly between treatments at harvest in two of the three Boneo short term trials. There were significant differences in EI (enrichment index) between some treatments in trials ST2, ST3 and ST4 at harvest. For example, SI increased for the chicken manure treatments relative to standard grower practice at transplanting in both of the trials where it was used. However, the effects of the other treatments on the nematode indices were inconsistent between trials.

Plotting the bidimensional space for EI/SI only showed a separation of treatments in the third trial (ST4) at transplanting, where untreated and standard practice treatments had lower structure (simpler food web) than the other treatments (Figure 6.13).

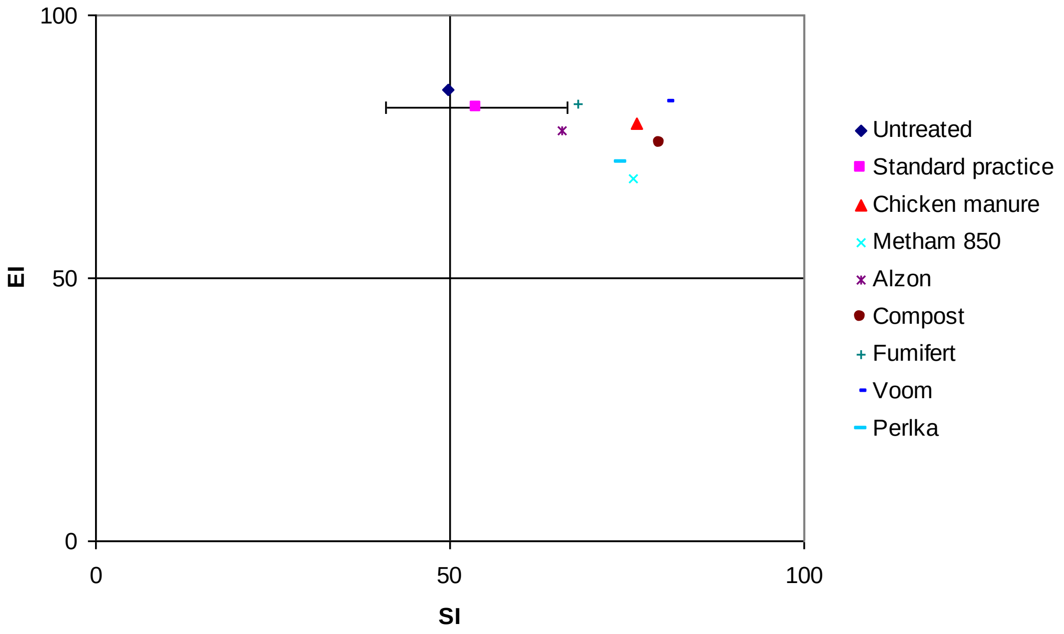


Figure 6.13 Bidimensional space for Enrichment Index (EI) v Structure Index (SI) for trial ST4 at transplanting. Error bars represent the LSD (5%).

6.3.3 Conclusions

- 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. In addition to profit increases, nitrification inhibitors reduce the potential for nitrate pollution of waterways and ground water and therefore are assumed more beneficial to soil health and the environment.

- Several treatments, the composts (green organic waste, chicken manure) and biofumigants (eg. Fumifert), that promote soil health produced equivalent or higher yields than standard grower practice or fumigation. The yield response and profitability was generally greater in summer than autumn probably due to the shorter crop 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 and this may improve soil structure.

- The treatments used in the short term trials only provided generally transient effects in biological activity and therefore long term disease suppression due to shifts in microbial populations is 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 (Section 6.5).

- Organic treatments tended to decrease pH and this confirms the findings of previous studies (Donald and Porter, 2008). 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.

6.4 Short term trial (ST5) - Tasmania

6.4.1 Methods

This trial (ST5) was carried out on a commercial vegetable farm located in Cambridge in southern Tasmania. The trial was set up and managed by Houston's Farm. A crop of red oak lettuce was grown according to the grower's normal practice with the addition of the treatments detailed in Table 6.8. All treatments were replicated five times in a randomized complete block design. Organic amendment treatments were applied on 5th and 6th August 2008. The organic amendments were applied at three rates, as 2.5, 5 and 10 cm deep layers of material laid onto plots and then incorporated into soil. The synthetic fertilizer treatments were applied on 7th August 2008. The lettuce crop was planted on 12th August 2008. Soil chemical and biological measurements were carried out as described in the general methods section.

Table 6.8 Treatments used in short term organic amendment trial in Tasmania (Trial ST5)

Treatment	Composition	Treatment rate
F2	40 % paper sludge 20 % green waste 40 % grape marc + Grate ash	2.5 cm
		5.0 cm
		10 cm
N3	60 % paper sludge 40 % pine bark + 100 kg/t fly ash	2.5 cm
		5.0 cm
		10 cm
N4	100 % paper sludge + 100 kg/t fly ash	2.5 cm
		5.0 cm
		10 cm
Commercial	Synthetic fertilizer[1] (Floranid® Masters) no compost	100 kg/ha
		200 kg/ha
		400 kg/ha
Untreated	no compost no fertilizer	

[1] All synthetic fertilizer treatments also included muriate of potash at 200 kg/ha

6.4.2 Results

Preliminary analysis showed that organic amendment rate and fertilizer rate did not significantly affect yield. Therefore, yield measurements and soil data were pooled across treatment application rates before analysis by ANOVA (Genstat 12).

Yield

The greatest head yield, salad yield and plant vigour/size rating occurred for F2 and N3 amendment treatments although the N3 had a significantly lower vigour/size score than F2 (Table 6.9). The N4 treatment also had significantly higher head yield and plant vigour/size score than the commercial treatment and untreated.

Table 6.9 Yield of red oak lettuce in Tasmanian organic amendment field trial

Treatment	Yield per whole head of lettuce (g)	Yield per head cut as salad (g)	Score for vigour/plant size
F2	354.7 a	107.3	4.667 a
N3	360.0 a	113.3	4.067 b
N4	289.6 b	101.7	3.867 b
Commercial	224.3 c	94.3	2.800 c
Untreated	198.0 c	89.1	2.733 c
LSD (P=0.05)	34.50		0.5026

Means within each column with no common letter differ significantly at p=0.05.

Soil Carbon

All measures of soil carbon were significantly increased by the addition of organic amendments relative to the commercial treatment and untreated (Table 6.10). There were no significant differences in the carbon values between the different carbon amendments.

Table 6.10 Effect of different organic amendments on soil organic matter composition.

Treatment	Total Carbon	Oxidizable organic Carbon	Total organic matter	Oxidizable organic matter
F2	3.70 b	3.53 b	6.83 b	6.50 b
N3	3.70 b	3.70 b	6.77 b	6.83 b
N4	3.77 b	3.63 b	6.97 b	6.73 b
Commercial	2.43 a	2.53 a	4.53 a	4.67 a
Untreated	2.33 a	2.40 a	4.33 a	4.43 a
LSD (P=0.05)	0.77	0.434	0.706	1.249

Means within each column with no common letter differ significantly at p=0.05.

Salinity and pH

Salinity, measured both as EC and TSS, was not different for the organic amendment treatments relative to the commercial treatment although both F2 and N4 had higher EC than the untreated (Table 6.11). The N4 treatment had significantly higher pH than the commercial treatment in $CaCl_2$, but pH in water was not significantly different.

Table 6.11 Effect of different organic amendments on soil salinity parameters.

Treatment	EC dS/m	pH $CaCl_2$	pH water	TSS (%)
F2	0.240 a	5.57 ab	6.27 ab	0.080 a
N3	0.193 ab	5.30 a	5.93 ab	0.063 ab
N4	0.217 a	6.27 b	6.80 b	0.073 ab
Commercial	0.197 ab	4.93 a	5.53 a	0.067 ab
Untreated	0.153 b	5.37 ab	5.97 ab	0.053 b
LSD (P=0.05)	0.0589	0.965	0.852	0.0228

Means within each column with no common letter differ significantly at p=0.05.

Macronutrients

All organic amendment treatments had increased ammonium nitrogen and increased total nitrogen relative to the commercial treatment and untreated (Table 6.12). The F2 and N3 treatments had lower nitrate nitrogen than the commercial treatment. Available phosphorus and available potassium were significantly higher in the F2 treatment than all other treatments.

Table 6.12 Effect of different organic amendments on soil macronutrients.

Treatments	Ammonium N (ppm)	Nitrate N (ppm)	Total N (ppm)	Olsen P (ppm)	avail K (ppm)
F2	4.83 a	8.3 a	0.26 a	73.7 a	723 a
N3	4.73 a	10.5 a	0.21 b	47.0 b	150 b
N4	4.00 a	22.3 ab	0.23 ab	48.7 b	150 b
Commercial	2.10 b	30.3 b	0.13 c	39.0 b	243 b
Untreated	2.40 b	21.6 ab	0.15 c	40.7 b	147 b
LSD (P=0.05)	1.573	15.67	0.043	10.78	105.7

Means within each column with no common letter differ significantly at p=0.05.

Cations

Potassium (both ppm and %) was increased in treatment F2 relative to all other treatments (Table 6.13, Table 6.14). Treatment N4 had increased calcium relative to the commercial treatment.

Table 6.13 Effect of different organic amendments on soil cation composition.

Treatment	Ca (ppm)	Ca:Mg	Mg (ppm)	K (ppm)	Na (ppm)	Sumof4
F2	5.63 ab	1.87 a	3.00 a	1.47 a	0.31 a	10.7 ab
N3	5.57 ab	1.97 a	2.93 a	0.32 b	0.28 ab	9.1 ac
N4	8.30 b	3.07 b	2.80 a	0.32 b	0.27 b	11.7 a
Commercial	4.20 a	1.77 a	2.37 a	0.49 b	0.11 c	7.2 ac
Untreated	4.93 a	1.97 a	2.43 a	0.31 b	0.13 c	7.8 bc
LSD (P=0.5)	2.49	0.994	0.907	0.259	0.029	3.24

Means within each column with no common letter differ significantly at p=0.05.

Table 6.14 Effect of different organic amendments on percentage soil cation composition

Treatment	%Ca	%Mg	%K	%Na
F2	53.7 a	28.7 a	14.33 a	3.00 a
N3	61.3 ab	32.3 a	3.67 b	3.33 ab
N4	71.3 b	23.3 a	3.00 b	2.33 b
Commercial	58.7 a	33.3 a	7.00 c	1.67 ab
Untreated	61.7 ab	32.3 a	4.33 bc	1.67 ab
LSD (P=0.5)	11.31	8.68	2.937	1.239

Means within each column with no common letter differ significantly at p=0.05.

Biological activity

There was a non-significant trend towards organic amendments increasing the biological activity of soils (as measured by FDA hydrolysis) compared with the untreated and commercial fertiliser treatments (Table 6.15).

Table 6.15 Effect of different organic amendments on soil biological composition.

Treatment	FDA µg F/Kg soil/h	% Bacterial Feeders (B)	% Fungal Feeders (F)	% Predators	EI	SI	CI	B/(B+F)	Parasitic nematodes	TFLN*
F2	1155 a	33.4 a	61.3 b	0	72.5 ab	35.5 a	40.3 ab	0.355 a	0 a	4450 ab
N3	1111 a	29.2 a	65.4 b	0	63.5 a	21.4 a	49.3 b	0.308 a	0 a	10290 b
N4	1234 a	39.1 a	53.8 b	0	75.2 ab	31.5 a	31.2 ab	0.422 a	140 b	9465 b
Commercial	1042 a	83.0 b	13.6 a	0	95.2 c	48.5 a	3.7 a	0.86 b	80 a	3238 a
Untreated	1088 a	61.1 ab	31 ab	0	85 bc	36.9 a	15.3 a	0.672 ab	254 a	3306 a
LSD (P=0.05)	296.7	0.3979	32.46	*	15.18	31.65	27.43	0.3334	283	5593.4

* total free living nematodes
Means within a column with no common letter differ significantly at p=0.05.

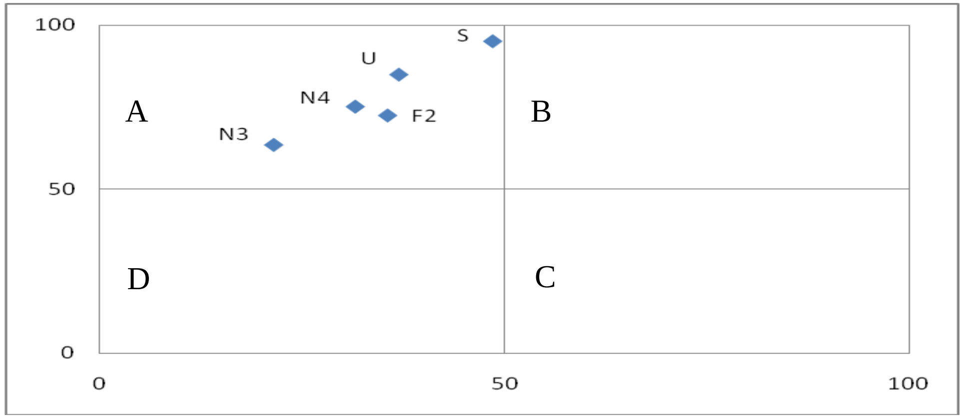


Figure 6.14 Nematode bidimensional space (EI vs SI) for different organic amendment treatments

Soils amended with organic matter had significantly higher populations of free-living nematodes compared with the synthetic fertiliser and untreated soils (Table 6.15). There was an increase in the proportion of fungal-feeders and corresponding decrease in bacterial feeding nematodes for the organic amendment treatments relative to the commercial treatment and untreated. Enrichment Index (EI), a measure of the available resources in the soil food web and the response of primary decomposers to those resources, was significantly higher in the commercial treatment than in the organic amendment treatments. SI, an indicator of the number of trophic layers in the soil food web, was similar in all treatments. CI, an indicator of slow organic matter decomposition mediated by fungi, was highest in all organic amended treatments.

The SI and the EI in a bidimensional space, allows classification of the soil food web and conditions into four states: Disturbed (quadrat A), Maturing (quadrat B), Structured (quadrat C) and Degraded (quadrat D). All treatment were classified as soil type A indicating a disturbed system (Figure 6.14).

6.4.3 Conclusions

Overall, all organic treatments increased yields over the untreated and commercial practice as well as improving the vigour of the crop. This may be related to the altered soil biology and chemistry (e.g. increased available P and non-leachable N). The results also showed that the composts led to positive increases in pH and Ca which may be useful treatments for control of clubroot if used in other crop production systems. Follow up studies by Houston’s Farm showed that the organic treatments led to a slightly shorter shelf life and that this may influence use of these products for some markets. Further studies are needed to determine the significance of such an effect.

6.5 Long term field trial No. 1 Boneo, Vic (Conventional Farm)

Aims: (i) To determine the long term effect of applying three organic amendments at a similar level of carbon and metham fumigation on profit, yield of broccoli (ie. plant productivity) and soil health characteristics.

(ii) To determine if the organic products could lead to a reduction in the need for fertilizer by increasing the cation exchange capacity and nutrient availability. This was done by reducing the fertilizer inputs across all treatments by 50%.

(iii) To determine if any build up in organic carbon could led to changes in microbial populations and increase diseases suppression (Chapter 5).

(iv) To determine if long term use of organic amendments could build organic carbon and have subsequent beneficial effects on suppressing clubroot and soil health (Chapter 7).

6.5.1 Methods

This long term field trial was conducted over 3 years (2008-2010) at a commercial vegetable farm in a loamy sand at Boneo on the Mornington Peninsula, Victoria. The crop rotation existed as a broccoli/celery rotation with applications of all organic products and fumigation applied before the broccoli followed by celery (2008 and 2009). Full yield and soil health assessments were made on the broccoli. The same organic and fumigant treatment were applied to the same plots over three cropping cycles as shown in Table 6.16. The organic products were initially calculated to be applied at rates equivalent to 10 t C/ha. However, due to differences in wet weights of products, carbon content and differences in rates of application the full amount of silage could not be applied practically. In the two following seasons, however, the rates of application of the organic products were standardized to 5 t C/ha as some treatments showed signs of phytotoxicity in the first season. Each treatment was replicated four times in a randomised block design. Fertilizer rate as shown below (Table 6.16) were applied at full rate or half rate of the standard grower practice to split plots. Synthetic fertilizer applications were reduced in the organic plots to allow for the nitrogen content of the organic material.

6.5.2 Results

Yield

The trial showed that three of the four organic amendments increased yields above the standard grower practice especially when the higher application rates of products were applied in 2008 (Figure 6.14). Chicken manure increased yields by up to 44% and these increases were greater in 2008 and 2009 when applied before the autumn sown crops. Compost and silage also increased yield on average around 12% compared to the standard grower practice. Yields in 2008 were significantly higher than both the standard grower practice and the metham sodium treatments (Table 6.17). This is most likely related to the high application rates of organic amendments added initially in 2008. The organic product lignite, however decreased yields by 26% (lignite high rate) when averaged over the three crops of the trial (Figure 6.15).

In the initial broccoli crop, there was a significant response in yield to the higher fertilizer rate with a mean yield of 7.63 kg/plot at 100% fertilizer and 6.81 kg/plot at 50% fertilizer. The impact of treatments on changes in soil carbon and other soil health parameters is discussed in Chapter 7.

Table 6.16 Treatments applied at or before transplanting and broccoli crop details for the long term field trial at Boneo, Victoria from 2008 to 2010

Treatment*	Products applied	Year 1 (LTY1)	Year 2 (LTY2)	Year 3 (LTY3)
Main Plots				
Standard practice	None			
Metham sodium	Metham Sodium	425 l/ha	425 l/ha	425 l/ha
Compost	Composted green waste	87.2 t/ha (14.4 t/ha C Eq[1])	26.2 t/ha (5 t/ha C Eq)	26.2 t/ha (5 t/ha C Eq)
Chicken manure	Composted chicken manure	66.3 t/ha (17.5 t/ha C Eq)	16.3 t/ha (5 t/ha C Eq)	16.3 t/ha (5 t/ha C Eq)
Silage	Ryegrass silage	19.9 t/ha (5.2 t/ha C Eq)	19.9 t/ha (5.2 t/ha C Eq)	19.9 t/ha (5.2 t/ha C Eq)
	Urea	40 kg/ha	40 kg/ha	40 kg/ha
Lignite high	Lignite	-	16.3 t/ha (5 t/ha C Eq)	16.3 t/ha (5 t/ha C Eq)
Lignite Low	Lignite	-	-	4.1 t/ha (1.25 t/ha C Eq)
Split Plots				
100% Fertiliser	*At Transplanting*			
	Rustica Gold Plus	356 kg/ha	356 kg/ha	356 kg/ha
	Boronated $CaNO_3$	225 kg/ha	225 kg/ha	220 kg/ha
	At Budding			
	Boronated $CaNO_3$	250kg/ha	250kg/ha	250kg/ha
50% Fertiliser	*At Transplanting*			
	Rustica Gold Plus	178 kg/ha	178 kg/ha	178 kg/ha
	Boronated $CaNO_3$	112 kg/ha	112 kg/ha	112 kg/ha
	At Budding			
	Boronated $CaNO_3$	125kg/ha	125kg/ha	125kg/ha
Crop parameters				
Transplanting date		8/7/08	26/3/09	20/12/09
Harvest date[2]		early Oct 08	23/6/09	17/2/10
Broccoli variety		Ironman	Belstar	Belstar
Rotation crop after broccoli		Celery	Celery	Silver beet

[1] Carbon equivalent; [2] Date of first broccoli cut; * A further application of $CaNO_3$ at 225 kg/ha was applied to all treatments at budding as per standard practice.

Table 6.17 Broccoli yields in the long term carbon amendment trial.

Main Treatment	Broccoli yield kg/plot		
	Year 1 (LTY1)	Year 2 (LTY2)	Year 3 (LTY3)
Standard practice	5.76 b	7.21 ab	11.61 a
Metham sodium	6.54 b	7.64 ab	12.31 a
Compost	7.56 a	7.53 ab	12.11 a
Chicken Manure	8.30 a	8.25 a	12.38 a
Silage	7.94 a	7.00 b	11.76 a
Lignite – high rate	-	5.48 c	8.31 b
Lignite – low rate	-	-	10.88 a
LSD (P=0.05)	1.009	1.149	1.702
Fertilizer effect	Sig	ns	ns
Interaction	ns	ns	ns
100% fertilizer	7.63		
50% fertilizer	6.81		
LSD (P=0.05%)	0.638		

Sig = significant (5% level), ns = not significant (5% level)

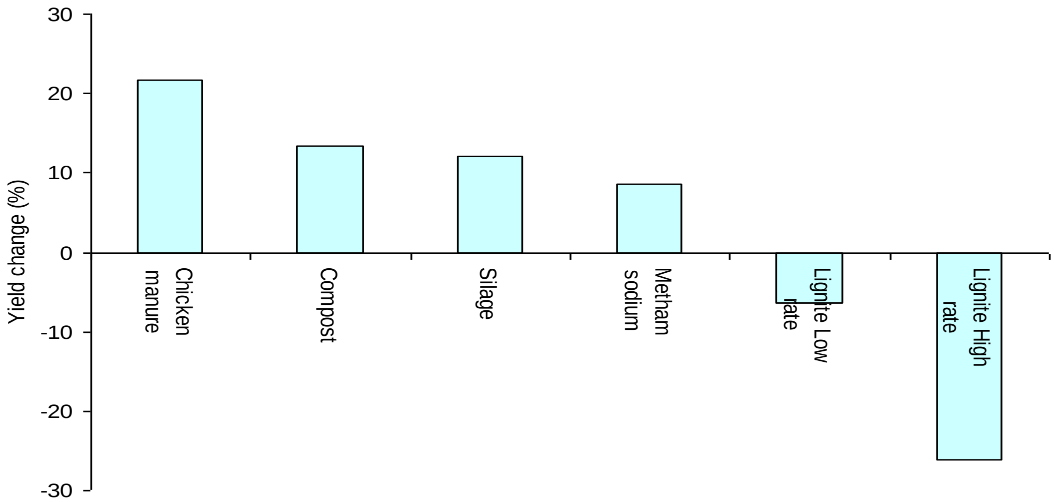


Figure 6.15 Mean yield changes (%) relative to standard practice over three seasons of long term carbon amendment trial. (The Lignite high rate is the mean of two season's data, Lignite low rate is one season's data).

In the 3rd year the impact of the high applications of organic products in year 1 (and to a lesser extent year 2) had been lost and none of the organic amendments promoted yields above those of the grower standard. As the 3rd year was a summer crop yields for all treatments tended to be higher. Also the cropping season is much shorter and this would enable the crop to make better use of the synthetic fertilizer applications.

Profit

As the rates of compost and chicken manure used in the first year of the long term trial were 3-4 fold higher than those used in the second and third years, average effects on profitability for these treatments were only calculated for years two and three (LTY2 and LTY3). Profitability increases of up to $3500/ha occurred for individual crops grown in soils treated with chicken manure relative to standard practice (Table 6.18).

Table 6.18 Effect of organic amendment treatments on the profitability of broccoli production in the long term Boneo trial.

Crop	Treatment	Treatment rate (T or L/ha)	Treatment unit cost [1] ($/T or L)	Additional treatment cost[2] ($/ha)	Broccoli Yield (kg/ha)	Income ($/ha)	Profitability relative to Standard practice ($/ha)
LTY1	Standard practice			0	7,114	12,804	-
	Chicken manure	66.3	33	2,188	10,251	18,451	3,459
	Compost	87.2	50	4,360	9,337	16,806	-359
	Silage	19.9	50	995	9,806	17,651	3,851
	Metham sodium	425	1.73	735	8,077	14,538	999
LTY2	Standard practice			0	8,904	16,028	-
	Chicken manure	16.3	33	538	10,189	18,340	1,774
	Compost	26.2	50	1,310	9,300	16,739	-599
	Silage	19.9	50	995	8,645	15,561	-1,462
	Metham sodium	425	1.73	735	9,435	16,984	221
	Lignite High rate	16.3	NA[3]	NA	6,768	12,182	NA
LTY3	Standard practice			0	14,338	25,809	-
	Chicken manure	16.3	33	538	15,289	27,521	1,174
	Compost	26.2	50	1,310	14,956	26,921	-199
	Silage	19.9	50	995	14,524	26,142	-662
	Metham sodium	425	1.73	735	15,203	27,365	821
	Lignite High rate	16.3	NA	NA	13,437	24,186	NA
	Lignite Low rate	4.1	NA	NA	10,263	18,473	NA

[1] Treatment costs do not include transport for compost and silage. Application costs have not been included for chicken manure, compost and silage treatments.
[2] Relative to standard practice treatment.
[3] Not applicable (product not commercially available)

Chicken manure application resulted in increased profitability relative to the standard practice treatment for all crops (Figure 6.16). While yield increases occurred for all crops treated with compost, the extra income generated did not cover the treatment cost and profitability relative to standard practice. Metham sodium fumigation increased profitability by approximately $520/Ha over the three crops. Profitability for the lignite treatments was not calculated because it is not a commercial product. However, the lignite treatments would have decreased profitability due to the yield reductions observed.

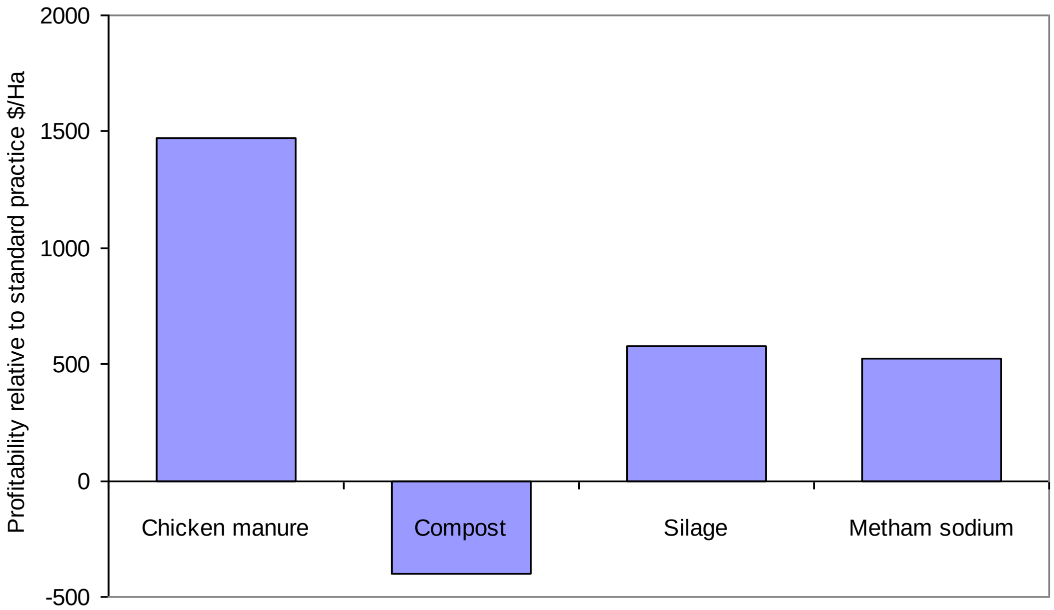


Figure 6.16 Average profitability* of treatments used over two (chicken manure and compost) or three (silage and metham sodium) broccoli crops in the long term trial relative to standard practice. *Only cost of the materials for the treatment was used to calculate profitability. Extra labour and fuel costs involved in applying the treatment were not included in the calculation with the exception of Metham sodium where application cost is included in the treatment cost.

Rotation Crop Yields

For the crops grown (celery, celery) between the broccoli crops assessed in the trials, there were no significant differences in yield between treatments (Appendices 6.43, 6.44 and 6.45).

Clubroot Disease

In the first two sowings of broccoli in the long term trial (LTY1, LTY2) there was very little clubroot development and disease severity was not significantly different between treatments (Table 6.19). This was anticipated when designing the trials as the aim was to determine the impact of treatments used for clubroot on yield and soil health in the absence of clubroot.

In the third year (LTY3), the chicken manure and high lignite rate treatments increased clubroot severity significantly. A smaller but still significant disease increase occurred for the low lignite rate treatment. Clubroot severity in the compost, silage and metham sodium treatments was not significantly different to the standard practice treatment.

Lignite was added to the trial in 2009 and although severity was low, this treatment had significantly higher clubroot than all other treatments.

Table 6.19 Clubroot severity at the long term Boneo trial. Clubroot severity scored on 0-3 scale where 0=0%, 1=1-10%, 2=11-50%, 3 = >50%

Main Treatment	Clubroot severity rating		
	Year 1	Year 2	Year 3
Standard practice	0.050	0.20 b	0.288 bc
Metham sodium	0.050	0.13 b	0.113 c
Compost	0.075	0.16 b	0.713 b
Chicken Manure	0.100	0.10 b	1.613 a
Silage	0.100	0.28 b	0.150 c
Lignite – High rate	-	0.58 a	2.050 a
Lignite – Low rate	-	-	0.875 b
LSD (P=0.05)	ns	0.287	0.486
Fertilizer effect	ns	-*	ns
Interaction	ns	-	ns

ns = not significant (5% level)
* not measured on low fertiliser treatments

Biology

Nematodes

At transplanting, there were no significant differences in any of the nematode parameters between treatments for all three broccoli crops. At harvest, some significant differences occurred for the nematode parameters SI, EI, CI, B:F, percentage predators and percentage free living nematodes (% FLN), but these were not consistent across years. Structure index (SI), a measure of the number of trophic layers in the soil food web, was significantly reduced for the chicken manure treatment relative to standard practice for the first crop of the trial indicating a less complex food web (Figure 6.17). Smaller and non-significant decreases in SI occurred for the other two organic amendments. In the next two years of the trial, there were no significant differences in SI although there was a trend toward reduced SI for chicken manure relative to standard practice.

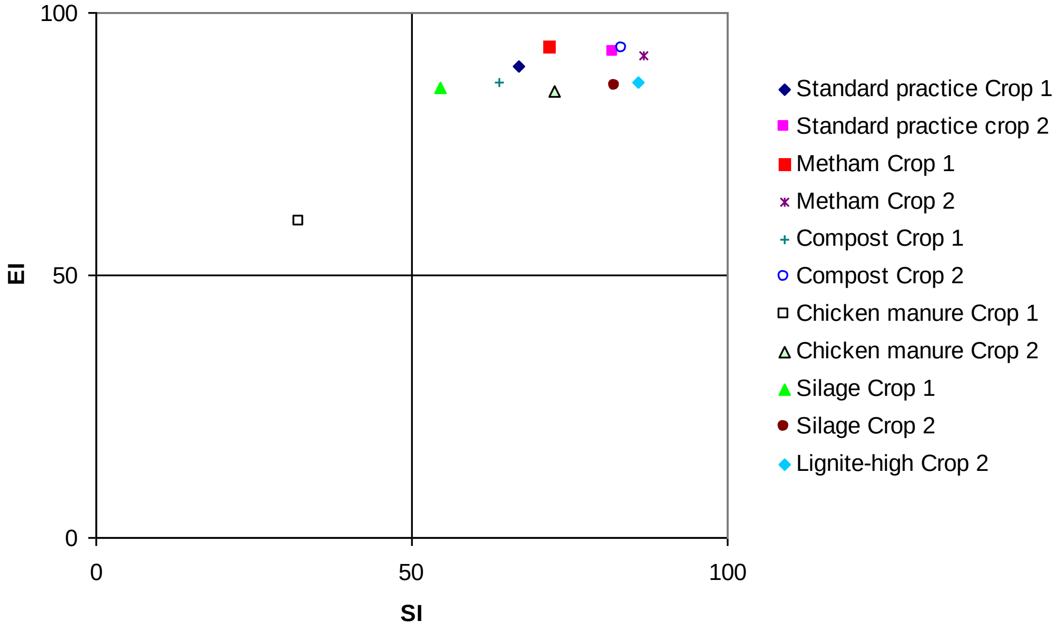


Figure 6.17 Enrichment index (EI) vs structure index (SI) for the long term trials at harvest

There were significant differences between nematode parameters between the two sampling times (transplanting and harvest) which reflect the disturbance to the system that occurs as part of the cropping cycle (Table 6.20).

Table 6.20 Mean values of nematode parameters in field soil collected at transplanting and harvest over the three broccoli crops in the Boneo long term trial (2008-2010)

Nematode parameter	Transplanting	Harvest
%Bacterial Feeders	88.0	62.3
%Fungal Feeder	5.9	9.4
%Omnivores	6.0	17.1
%Free Living Nematodes	97.9	88.2
% Predators	0.11	0.40
B:F (bacterial/(bacterial+fungal)	0.94	0.87
CI - Channel index	2.0	6.6
EI - Enrichment index	94.8	83.8
SI – Structure index	0.82	1.45
H' – Shannon Wiener diversity index	52.1	67.8

Soil biological activity

Respiration and FDA activity were generally increased by the application of carbon amendments relative to standard practice treatment (Figure 6.18, Figure 6.19Figure 4.1). The chicken manure treatment resulted in the largest increase in both parameters, followed by silage and then compost. The largest increases occurred at transplanting although respiration rate was still elevated above standard practice for chicken manure, compost and silage at harvest.

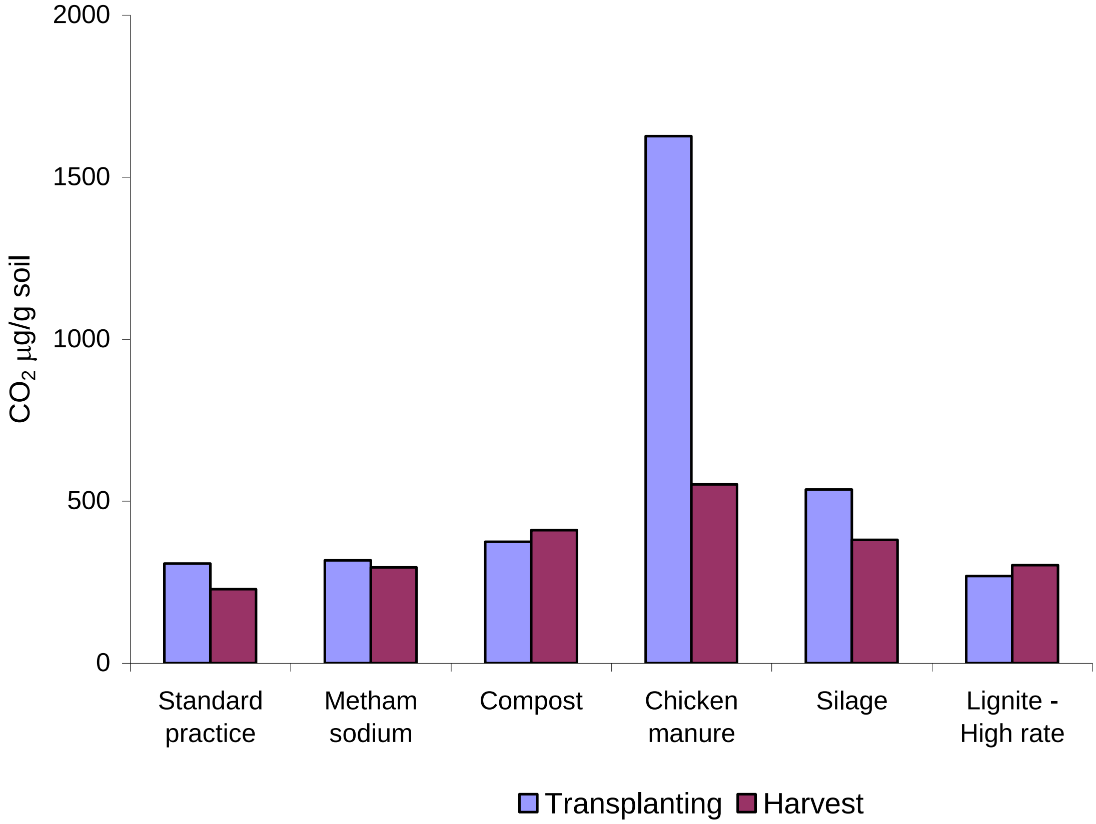


Figure 6.18 Mean soil respiration (CO_2 evolution) measured at 4 days for year 1 and year 2 of the long term Boneo field trial. The lignite-high rate treatment was not applied in year 1.

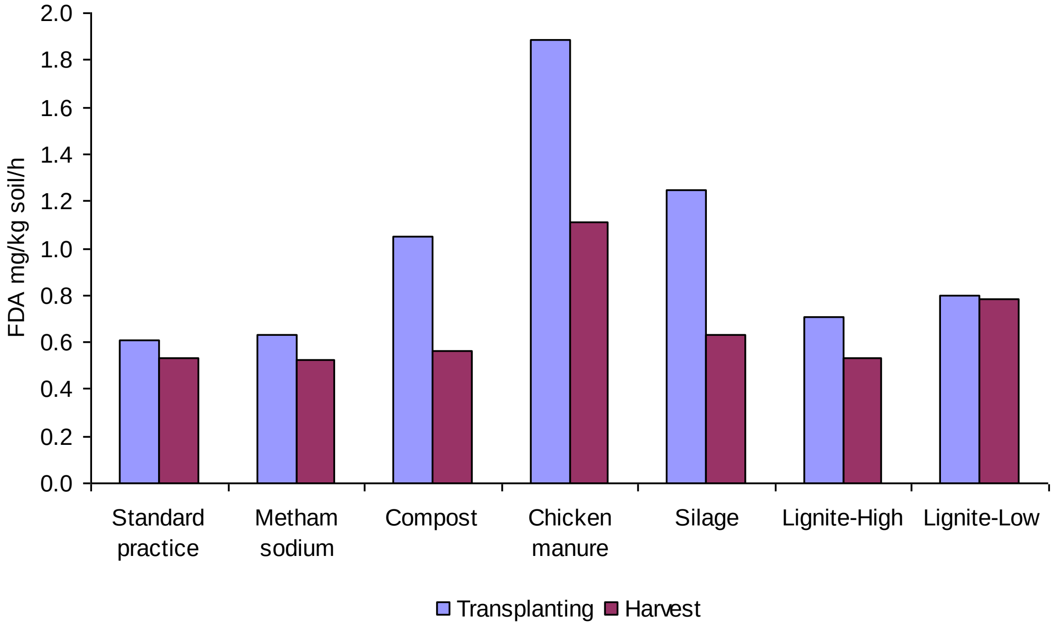


Figure 6.19 Mean FDA lipase activity for the three seasons of the long term Boneo trial, The lignite-high rate treatment was not applied in year 1, the lignite-low rate treatment was only applied in year 3.

Labile carbon also generally increased for all organic amendment treatments at transplanting and remained elevated at harvest (Figure 6.20). Increased biological activity in organic amended soils may have the benefits of increased disease suppression and more rapid turnover of nutrients from organic matter.

Figure 6.20 Mean labile carbon for year 1 and year 2 of the long term Boneo field trial. The lignite (high rate) treatment was not applied in year 1.

pH
In general, addition of carbon amendments (with the exception of silage) decreased soil pH relative to the standard practice treatment (Figure 6.21). The chicken manure treatment did not result in a significant reduction in the first year (LTY1) at harvest but did at all other samplings. The application of the lowest rate of lignite did not reduce pH significantly but the high rate did in both trials where it was applied.

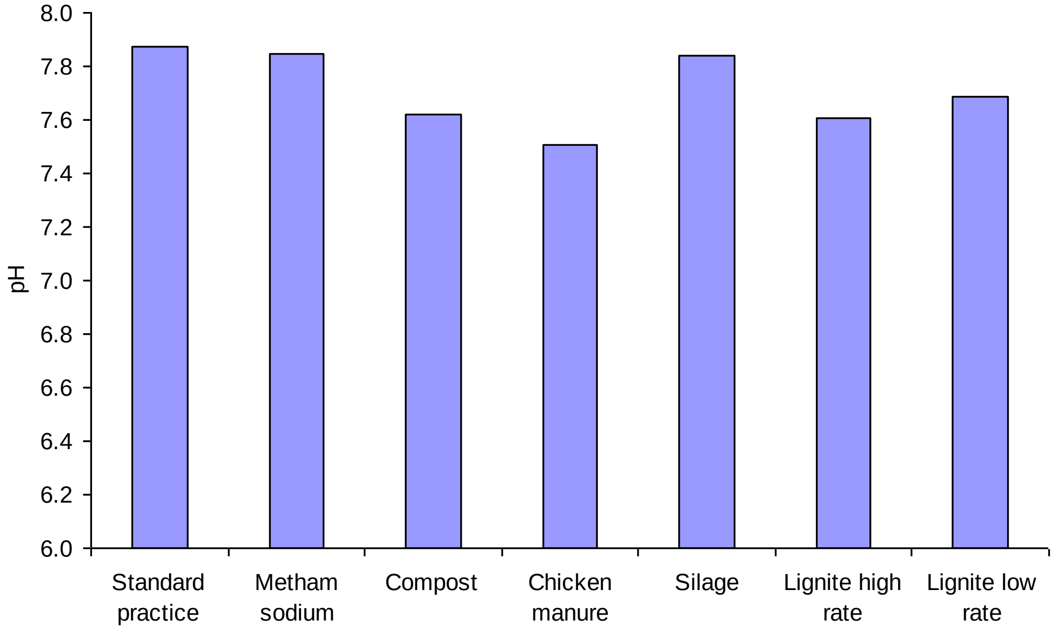


Figure 6.21 Mean pH (water) values at 0-15 cm depth for the long term Boneo field trial (average over the three years (except for lignite high rate and lignite low rate which were averaged over two years and one year, respectively).

There appeared to be an inverse relationship between soil pH and clubroot severity with increased clubroot severity observed at lower pH (Figure 6.22).

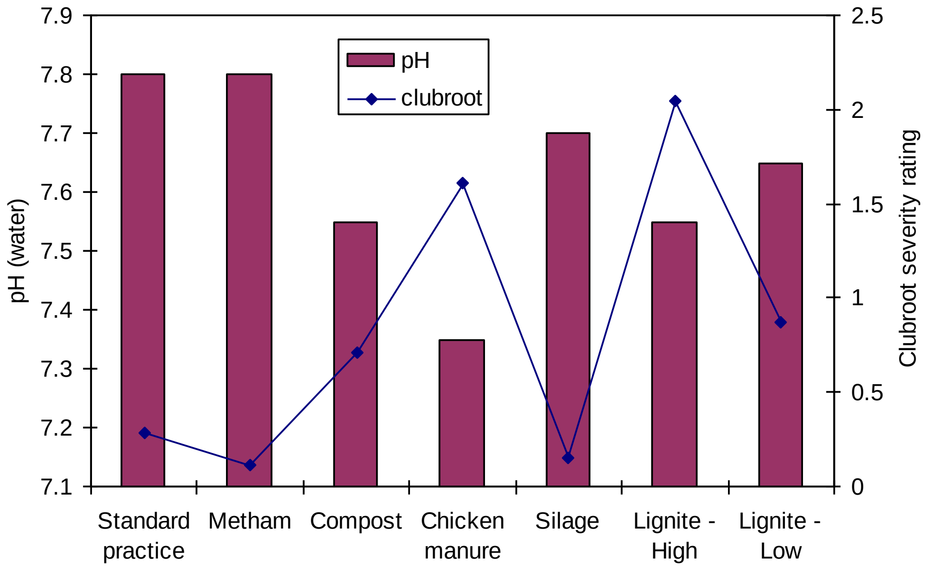


Figure 6.22 Mean pH (averaged over both transplanting and harvest measurements) vs clubroot severity rating at harvest for the third season of the long term trial (LTY3)

Chemistry

Soil Carbon

The four measures of soil carbon (total carbon, total organic matter, oxidizable carbon, oxidizable organic matter) were all very highly correlated. Soil total carbon and oxidisable organic carbon were within 10% of each other indicating low inorganic carbon content (and also low non-oxidisable carbon i.e. charcoal content). Therefore, only differences in total carbon will be discussed here. Total carbon was increased by the addition of organic amendments in the order compost > Lignite high rate > chicken manure > Silage = Lignite low rate. The effect of timing (transplanting or harvest) was not significant.

There did not appear to be a strong cumulative effect of the addition of carbon amendments on soil total carbon over time (Figure 6.23). However, total carbon in the silage treatment tended to increase with time. Similar increases in total carbon also occurred in the two treatments without carbon amendments (standard practice and metham sodium).

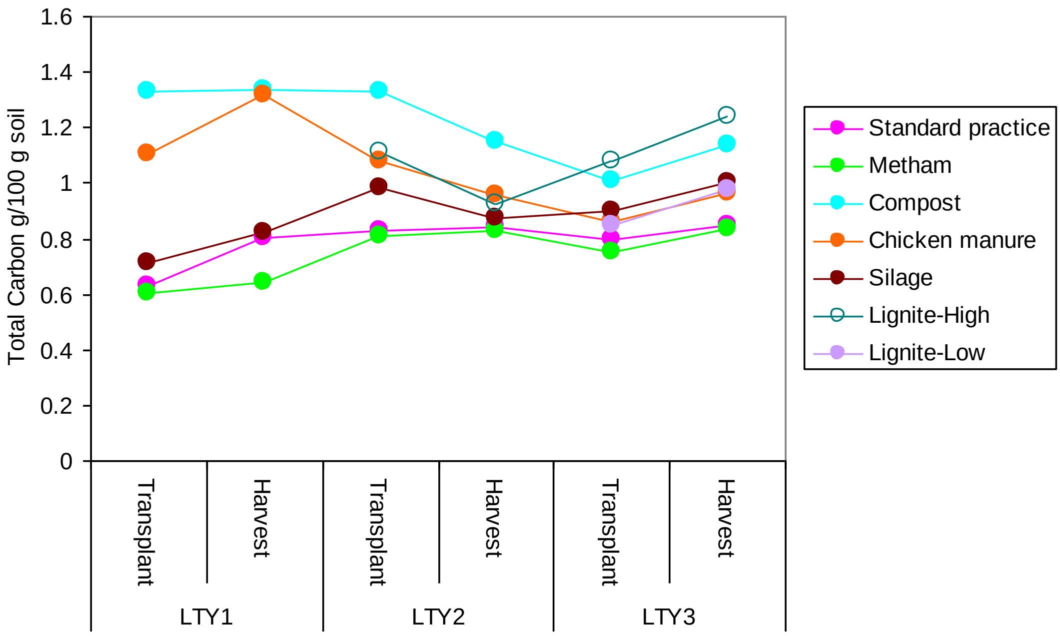


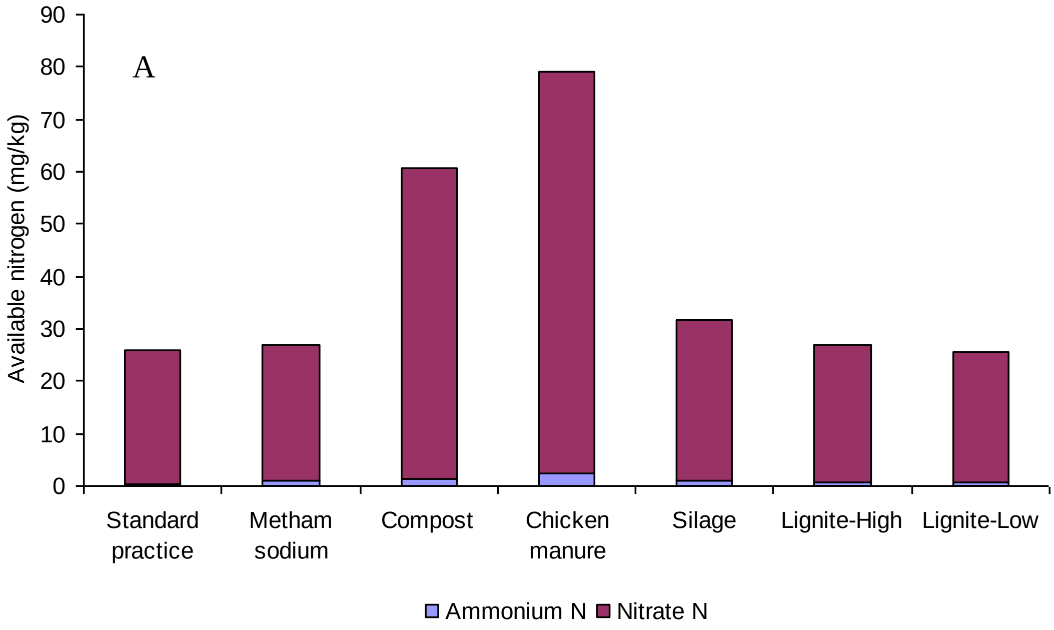
Figure 6.23 Soil total soil carbon in the long term Boneo field trial. (0-10 cm depth)

Available nitrogen

Nitrate nitrogen was the dominant form of plant available nitrogen at all sampling times with only small amounts of ammonium nitrogen present. Ammonium nitrogen was only significantly increased relative to standard practice by the chicken manure treatment in the first season (LTY1) at both transplanting and harvest. The application rate of chicken manure in this first crop was approximately three times higher than in the subsequent seasons (LTY2 and LTY3) where ammonium levels were not significantly higher than the standard practice treatment.

Chicken manure resulted in an approximately three fold increase in available nitrogen at transplanting relative to the standard practice treatment, followed by the compost treatment which resulted in a two fold increase (Figure 6.24 A). The silage treatment only had slightly increased available nitrogen relative to standard practice at transplanting.

At harvest, chicken manure, silage and compost all had increased available nitrogen relative to standard practice on average (Figure 6.24 B) although results were variable for the different cropping seasons. This suggests that these organic amendments may have the potential to allow lower nitrogen fertilizer inputs by growers.



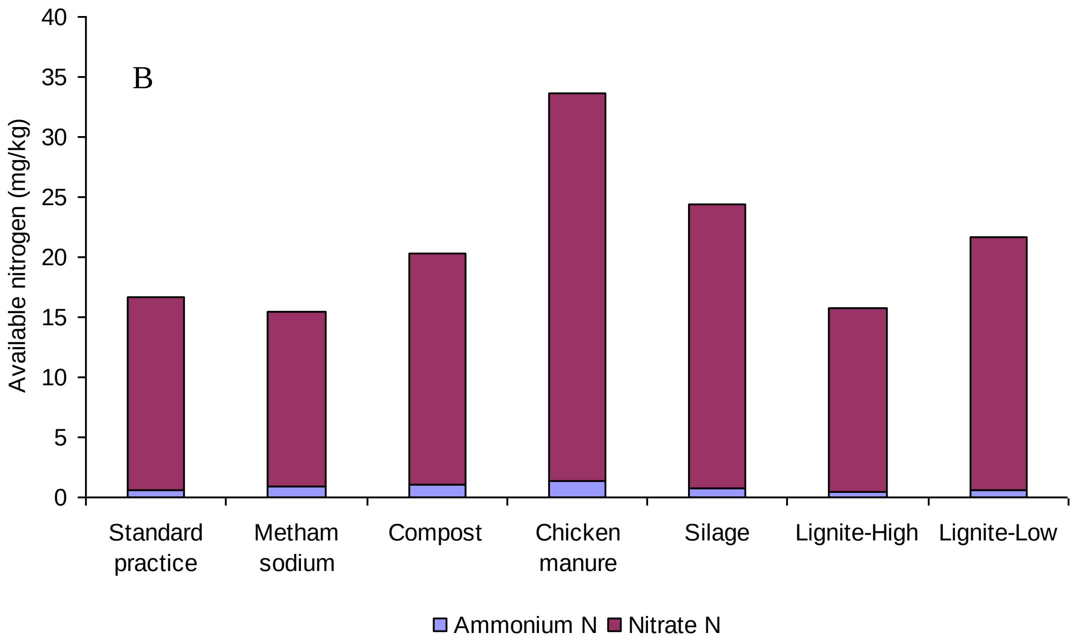


Figure 6.24 Mean available nitrogen at A) Transplanting and B), Harvest for the two crops of the long term trial (except Lignite-Low which was only a single crop)

Total Nitrogen was significantly higher in the compost and chicken manure treatments relative to the standard treatment at both crop stages in the first year of the trial and at transplanting in the second year (Figure 6.25). At the other samplings there were no significant differences in total nitrogen between treatments.

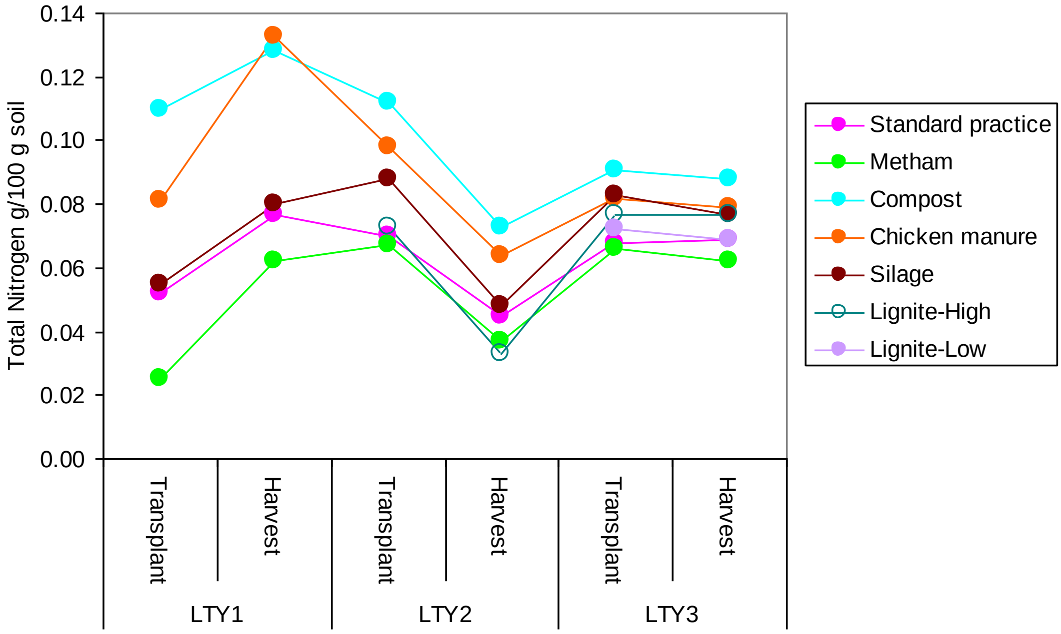


Figure 6.25 Soil total nitrogen concentrations in the Boneo long term field trial. (0-10 cm depth).

Phosphorous (Olsen)
Available phosphorous was well in excess of requirements for vegetable crops for all treatments at all sampling times (i.e generally >90 mg/kg). This suggests that phosphorus fertilizer inputs could be reduced without affecting yield. Phosphorous was increased relative to the standard practice treatment by the chicken manure treatment at all sampling times except for the third year (LTY3) at harvest when applied in combination with 50% fertilizer. The composted organic mulch treatment only had significantly increased phosphorous in the third year (LTY3) at transplanting.

Potassium
The addition of all organic amendments, with the exception of lignite, significantly increased available potassium relative to the standard practice treatment in at least one crop in the long term trial. Available potassium was higher at transplanting than harvest and increases due to the addition of organic amendments were the largest at transplanting (Figure 6.26). The increase was greatest for the chicken manure, followed by the compost and lignite treatments at transplanting. However, at harvest, the compost treatments had the highest available potassium. This suggests that organic amendments have the potential to reduce potassium fertilizer requirements for vegetable crops.

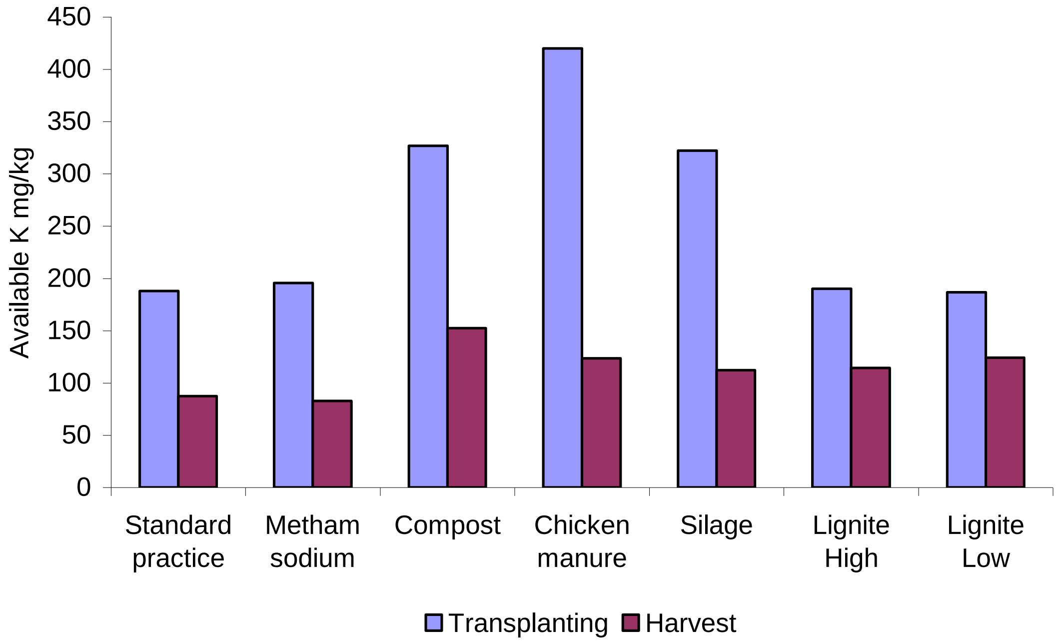


Figure 6.26 Mean available potassium for the long term field trial (averaged over the three crops).

Other Major Cations

Calcium was not significantly different between treatments at all sampling times except for the chicken manure treatment in the first year which had significantly higher levels than all other treatments (with the exception of Metham sodium at 100% fertilizer). There was a trend towards increased total magnesium and potassium concentrations in soil with the addition of organic amendments compost, chicken manure and silage relative to standard practice (Figure 6.27). These organic amendments tended to decrease the Ca:Mg ratio for the compost and chicken manure treatments.

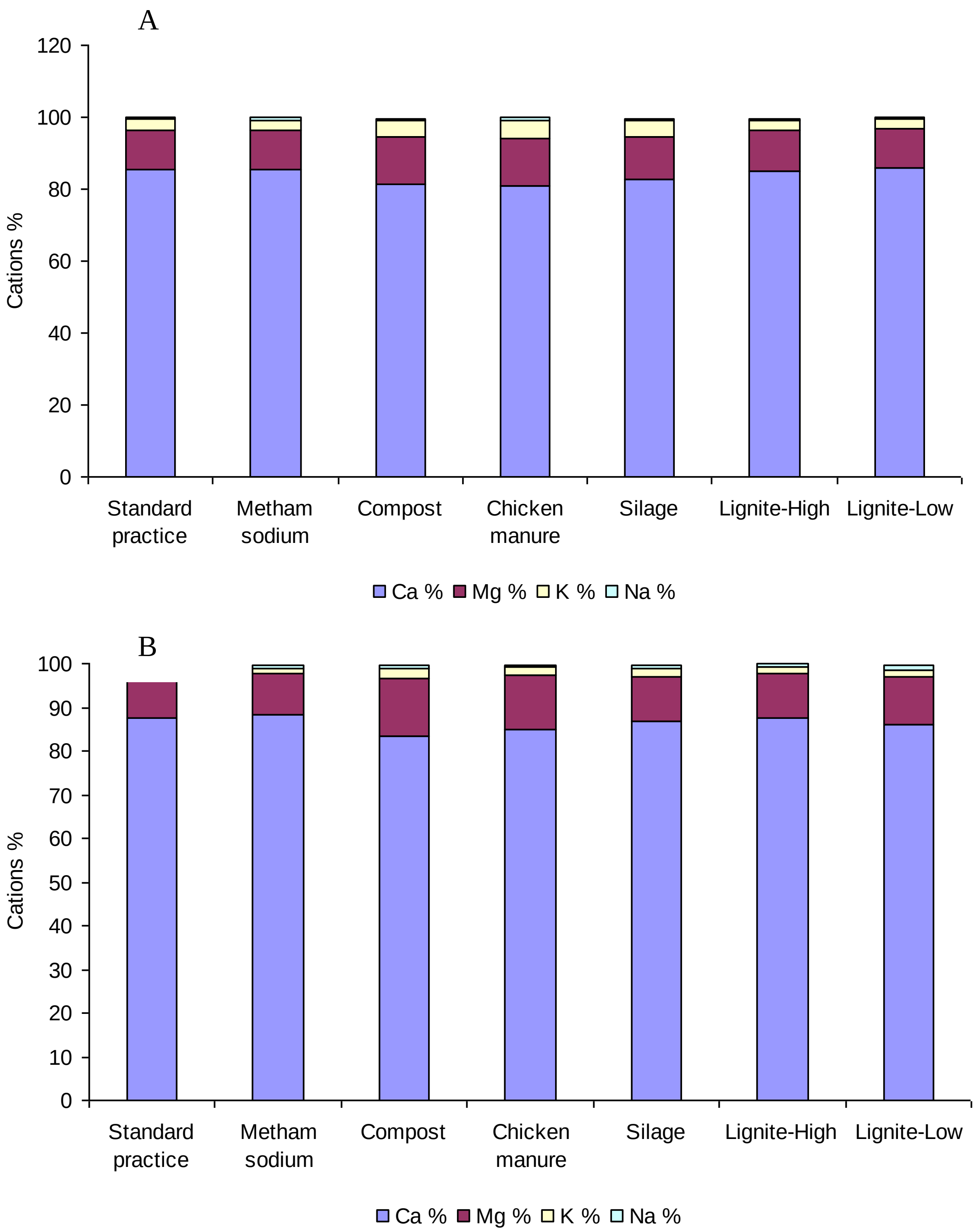


Figure 6.27 Soil major cations as percentages for the long term trial at A) transplanting and B) Harvest

Salinity

Electrical conductivity (EC) and percent total soluble salts (%TSS) were highly correlated. Generally the chicken manure treatment increased levels of both parameters relative to the standard practice at all sampling times. The compost treatment increased levels only at transplanting. Silage only increased levels in the second year (LTY2) at both transplanting and harvest.

Micronutrients

Available sulphur increased in the compost and chicken manure treatments relative to standard practice at transplanting (Figure 6.28). At harvest, there were generally no significant differences between treatments, with the exception of one crop (LTY2) where chicken manure had increased sulphur. The chicken manure treatment had significantly higher copper, manganese and zinc than standard practice in most trials (Appendices 6.26-43). The compost treatment had significantly higher iron and zinc than standard practice (Appendices 6.26-43). The silage treatment had significantly higher manganese than standard practice for the second two crops but not the first (Appendices 6.26-43).

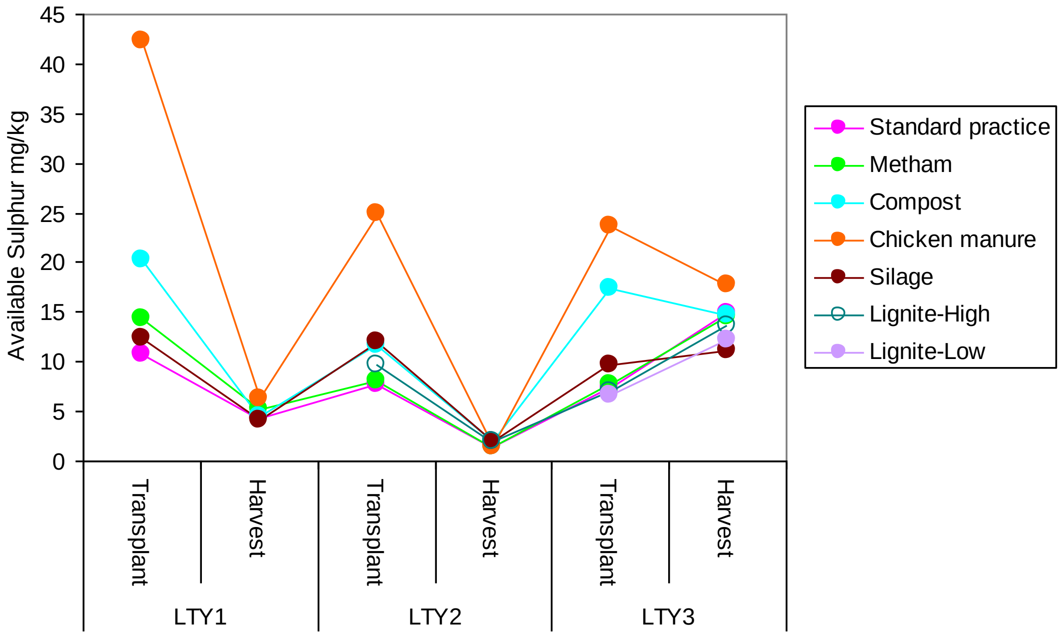


Figure 6.28 Soil available sulphur (S) for the long term Boneo field trial (0-10 cm depth)

Leaf nutrients

Nutrient levels in leaves were measured in the final season of the trial (LTY3) (Table 6.21). Only the levels of some micronutrients were significantly different between treatments. There was no significant effect of fertilizer rate. Boron was lower in treatments which had higher clubroot severities (compost, chicken manure and lignite) (Figure 6.29).

Table 6.21 Micronutrient concentrations in leaf tissue at harvest in trial RL6

Treatment	Sodium (%)	Aluminium (ppm)	Boron (ppm)	Manganese (ppm)	Iron (ppm)
Standard grower practice	0.963 a	4.50 a	43.50 a	22.67 ab	90.8 a
Metham sodium	0.888 abc	4.67 a	43.00 a	24.67 ad	86.5 ac
Composted organic Mulch	0.968 a	1.50 b	36.33 b	19.33 b	71.2 bd
Fresh Chicken Manure	0.778 bc	1.50 b	36.67 b	23.17 ac	79.2 bc
Silage	0.928 ab	0.87 b	43.98 a	24.00 ad	75.3 bd
Lignite – High rate	0.943 a	1.00 b	35.67 b	21.17 bc	67.3 d
Lignite – Low rate	0.736 c	3.73 a	38.75 ab	26.83 d	113.0 e
LSD	0.1525	1.602	6.705	2.974	11.12

Values within a column followed by the same letter are not significantly different at the 5% level

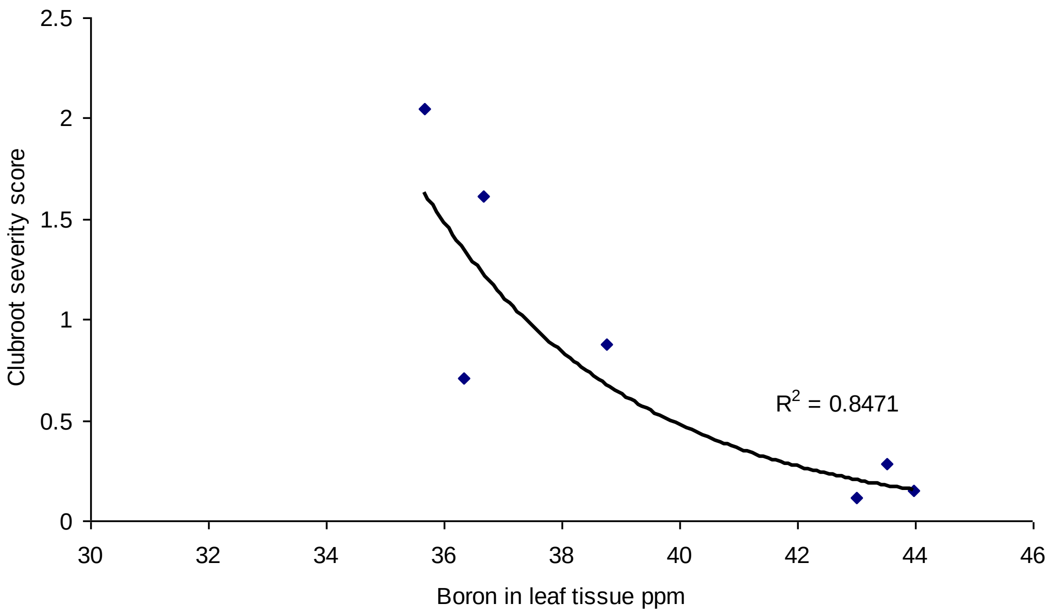


Figure 6.29 Boron concentration in leaf tissue vs clubroot severity at harvest for the third crop of the long term trial (LTY3).

6.5.3 Conclusions

In the long term trial there was a trend towards increased yield relative to standard practice for the organic amendments compost, chicken manure and silage. Metham sodium fumigation increased yield to a lesser extent. The greatest yield increases occurred in the first year of the trial when higher rates of all organic amendments were used. The application of lignite reduced yield relative to the standard practice treatment.

Profit increases of up to $3000/ha occurred with the addition of organic amendments for individual crops but there were no consistent increases in profitability over the course of the long term trial. Overall, chicken manure was cost neutral and silage only reduced profitability (by approximately $200/ha). Compost resulted in yield increases, but the high cost of the material resulted in a relatively large decrease in profitability relative to standard practice.

In the first two years of the trial, clubroot severity at harvest was very low. In the third year of the trial when a broccoli crop was grown over summer (temperatures more conducive to disease), chicken manure and both rates of lignite increased clubroot severity relative to the standard practice treatment. Composted organic mulch had significantly greater clubroot severity than both the metham sodium and silage treatments, but this increase was not significantly different to the standard practice treatment. Soil pH was decreased by varying degrees by the different organic amendments and decreased pH and leaf boron levels were associated with increased clubroot severity. The pH effect on clubroot may be mitigated by reformulating the amendments or co-applying lime.

Increased soil levels of available plant macro nutrients, in particular potassium, nitrogen and phosphorus, were observed for organic amendments. In addition, the increased biological activity occurring from organic amendments may increase mineralization of nutrients from organic matter decreasing reliance on chemical fertilizer inputs.

Soil carbon was increased by the addition of organic amendments with the greatest increases occurring for compost followed by the high lignite rate and then chicken manure then silage. The increases relative to the standard practice treatment were greatest at the start of the first year of the trial (up to 100%) when higher rates of the organic amendments were used (11-20 t/ha carbon) compared to year 3 when increases were up to 50% when lower amendment rates were used (5 t/ha of carbon). Between crops, however the organic carbon did not build to higher levels with subsequent applications of organic amendments. This finding is very important as it shows that tillage and crop management are burning off the carbon and that minimising tillage could have significant effects in these soils. This is anticipated to be examined in future studies.

Further work is required to optimise the application of organic amendments for vegetable production and ensure their application is made at the right time of year when the crop and the soil can maximise the benefits of application. Results suggest that the organic amendments have improved soil health (increased biological activity, increased organic matter and lower fertilizer requirements) however three of the four amendments promoted clubroot disease due to a fall in pH and lower boron content. Future trials need to find ways to offset this negative effect.

In conclusion, this trial showed increased yield benefits from use of organics. Their use was highly profitable when used before an autumn crop and when the products were applied at high rates above 10 t C equivalent. If applied this way the organic treatments were as effective as metham sodium fumigation and provide a more sustainable production method for growers.

6.6 Long term trial No. 2, Devon Meadows, Vic (Sustainable Farm)

Aim: The overall aim of this trial was to assess the impact of different cropping practices on soil health at a sustainable grower's property on a sandy loam soil in Victoria. A field trial over 4 crop rotations was conducted to determine the effects of different soil amendments incorporated with rye corn on yield and disease and a number of soil chemical and biological indicators.

Specific Aims:

(i) To identify if different combinations of organic amendments and crop rotation with rye corn could improve yield and soil health.

(ii) To investigate which organic amendment groups (organics, biofumigants, fumigation) best promoted yields. The trial compared fumigation with biofumigants applied as solid products or liquids, and other organic products which had no biofumigant effect.

(iii) In particular, treatments were selected to consider whether changes in soil biological activity could be identified under two different rotation systems and soil management regimes.

(iv) Effects on soilborne disease suppression and yield were monitored over four cropping seasons.

This trial compared two different groups of soil amendments: seven organic inputs (compost, vetch green manure crop, humic acid, seaweed amendment, green waste from a lettuce crop, and two biochars) and six biofumigants (two green waste from leek and *brassica*, mustard oil, mustard seed meal, pine oil and neem cake). All these treatments (split plots) were applied to either fallow ground or following a rye corn crop rotation (Main plot).

6.6.1 Materials and Methods

The field experiment was established on a commercial vegetable farm of 200 ha at Devon Meadows, 50km SE of Melbourne (38x 10' 56.10'' S; 145x 19'33.95''E), Victoria. The soil at the site was a Cranbourne sand, described as a Pipey Podosol using the Australian Soil Classification system (Isbell 1996): dark brown: fine sandy clay loam: weak to strong (dry) and very firm (wet) consistency: many very fine macrospores: slakes, no dispersion.

A preliminary chemical report conducted on the six plot replicates before the incorporation of the first soil amendments (15/04/2008) showed that the labile carbon was at an adequate level for vegetable production (667.7 ± 69.0) (Table 6.22).

Table 6.22 Pretreatment labile carbon for the six plot replication fields

	Labile C ppm)
PS plot1	747.9
PS plot2	700.3
PS plot3	591.3
PS plot4	703.4
PS plot5	688.9
PS plot6	574.3
mean	667.7
DESV	69.0

.

Treatments and experimental design.

During the trial, four different crops (Table 6.23) were grown over three growing seasons from 2008 to 2010. The trial area covered 2160 m^2 with experimental plots of 12 m^2 (10 m x 1.2 m). The blocks were defined by sprinkler rows (14.4 m wide x 50 m long), with 6 blocks containing 30 treatments each.

Soil beds were prepared before the soil was amended with either a fumigant, organic amendment or biofumigant input.

Main treatments – Rye corn or fallow
There were two crop rotations during the trial with rye corn (sowing rate 50 kg/ha). The rye corn was sown three months before the first two main crops were planted. These were sown to fit with the winter season and the regular crop management by the grower.

The sub plot treatments consisted of 6 biofumigants, 7 organic amendments, untreated and the synthetic fumigant (Table 6.24). The soil amendments were applied prior to planting of each crop and the same treatments were applied to the same plots over the four cropping cycles (Figure 6.30). A replicated block design was employed, comprising 6 blocks with fifteen sub-plot treatments (x 2 main treatments = 30 subplots/block).

Table 6.23 Rotational history and cropping timeline in the study.

Trial codes	Rotation	**Crop**	**Planting**	**Harvest**
PS1	Crop 1-2008	Lettuce	30 June	2 September
PS2	Crop 2-2008/09	Endive	9 December	26 January
PS3	Crop 3-2009	Leek	3 March	24 August
PS4	Crop 4-2009/10	Parsnip	16 November	26 March

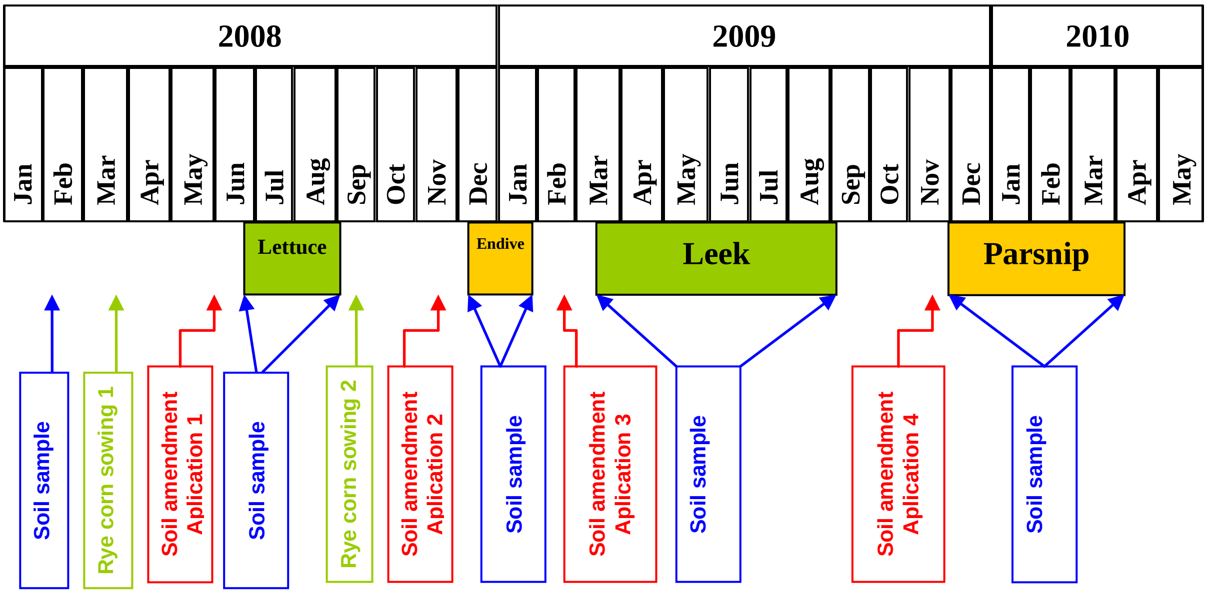


Figure 6.30 Timeline for crop management of the long term trial at Devon Meadows. The blue lines (I) show the 9 sampling dates for assessing indicators of soil health changes. The green (I) lines show approximately when rye corn was applied as a rotation crop to add mulch to the plots and the red line (I) shows when the soil amendments were added to soil.

Table 6.24 Split plot treatments. Treatment and rates of soil amendments applied over the four crop cycles.

Treatments	Treatment codes	Dose rate
CONTROLS		
1)Untreated	U	untreated
2) Dazomet (fungicide)	D	400 kg/ha
ORGANIC INPUTS – Solids		
3) Compost	C	10 t/ha
4) Green waste (leek)	GW2	5 t/ha
5) Green waste (brassica)	GW3	5 t/ha
6) Green waste (lettuce)	GW1	5 t/ha
7) Vetch green manure crop	V	sowing rate 100 kg/ha
8) Biochar type 1 (parent material: Hard wood chip)	BC1	10 t/ha
9) Biochar type2 (parent material: Chicken manure)	BC2	10 t/ha
ORGANIC INPUTS – Liquids		
10) Humic acid treatment,	HA	5 L/ha
11) Seaweed amendment (Seasol)	SS	5 L/ ha
BIOFUMIGANTS and Oils		
14) Pine oil (interceptor)	PO	90L/ha as a 10%solution
12) Mustard oil (Vigour)	MO	50 L/ha
13) Mustard seed meal (Fumafert)	MM	2 t/ha
15) Neem cake	N	0.6 t/ha

Trial assessments.
Before incorporating the soil treatment at planting and harvest, disease incidence, soil chemical properties, soil biological indicators, and microbial activity were determined. Soil microbial activity was assessed by measuring using fluorescein diacetate hydrolysis as previously described.

Yield and disease assessment.
Vegetables were harvested from the centre three beds of each plot (4.2m x 7m) for yield and disease assessment. The yield was evaluated as the number and weight of marketable and non marketable plants harvested per plot. If diseases were present, the incidence was assessed as the percentage of plants showing disease symptoms.

Soil assessment: (physical, biological and chemical).

Soil was collected by pooling 10 cores (5 cm diam x 10 cm depth) from the centre row of each. This ensured soil was collected from the root zone. The pooled soils of approximately 2 kg were stored at 4 ºC before testing. Soil chemical and biological testing was carried out as previously described (see chapter 4).

Statistical analysis
Data were analysed by analysis of variance (ANOVA) using Genstat 12. Prior to analysis, where required, data were subjected to a $\log_{10}$-transformation to improve homogeneity of variance. If treatment and split plot treatment interactions were non-significant, data from each split plot treatment (fallow and rye corn) were pooled and analysed together.

Multiple regression analysis was carried out with (i) yield and disease incidence and (ii) soil microbial activity on time and soil carbon contents.

6.6.2 Results and Discussion

Yield
There was a significant main treatment effect of ryecorn on lettuce yield in the first harvest (PS1). This effect was evident when ryecorn was applied alone (untreated), when it was followed by a fumigation (dazomet) or when it was followed by applications of a solid organic product, either added as biofumigants or standard carbon amendments at high rates (from 0.6 t of dried material to 20 t of fresh weight (Figure 6.31). The same response was not observed when the rye corn incorporation was followed by Vetch, humic acid, Seasol® or the two biofumigant oils.

The above result suggests that when significant amounts of solid products were added to soils after the initial rye corn mulching, the soil had more nutrients available for crop growth. Possibly incorporation of rye corn provided nutrition that allowed the build up of soil microbial populations so that they were able to degrade the solid organic amendments more effectively, thus releasing greater amounts of nutrients from the organic products and contributing to gains in yield.

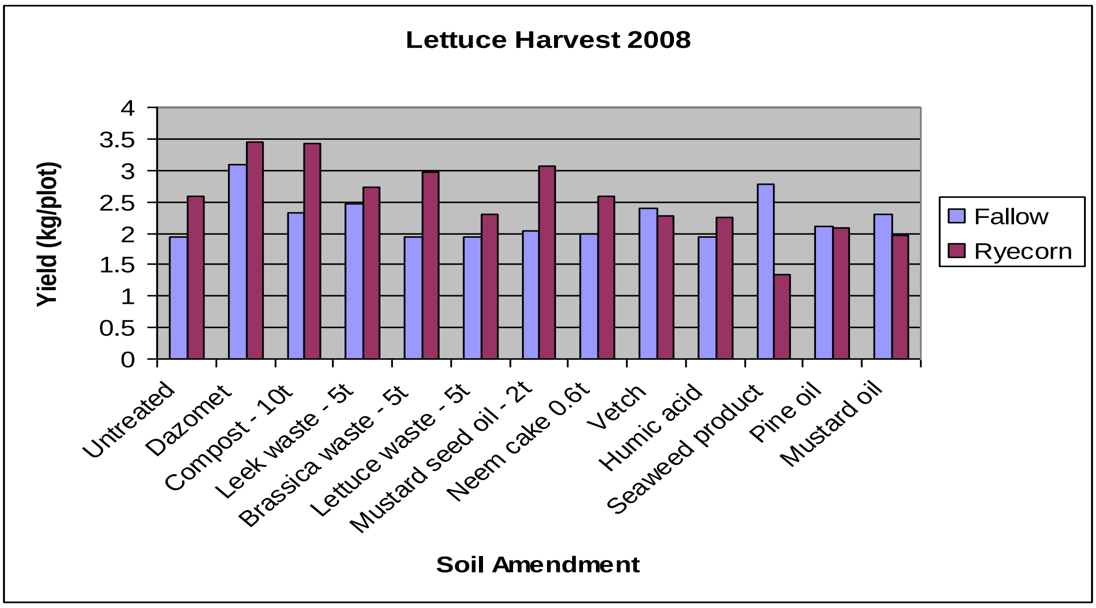


Figure 6.31 The effects of different organic amendments and other treatments on the yield of lettuce at Devon Meadows in 2008.

This effect, however, was not evident in the second crop, endive, which was sown in summer (Figure 6.32). No further rye corn plantings were made for the latter crops due to the difficulty of fitting it into the long cycle for leeks and parsnips. There was also no residual effect of rye corn mulching for these crops (Figure 6.33).

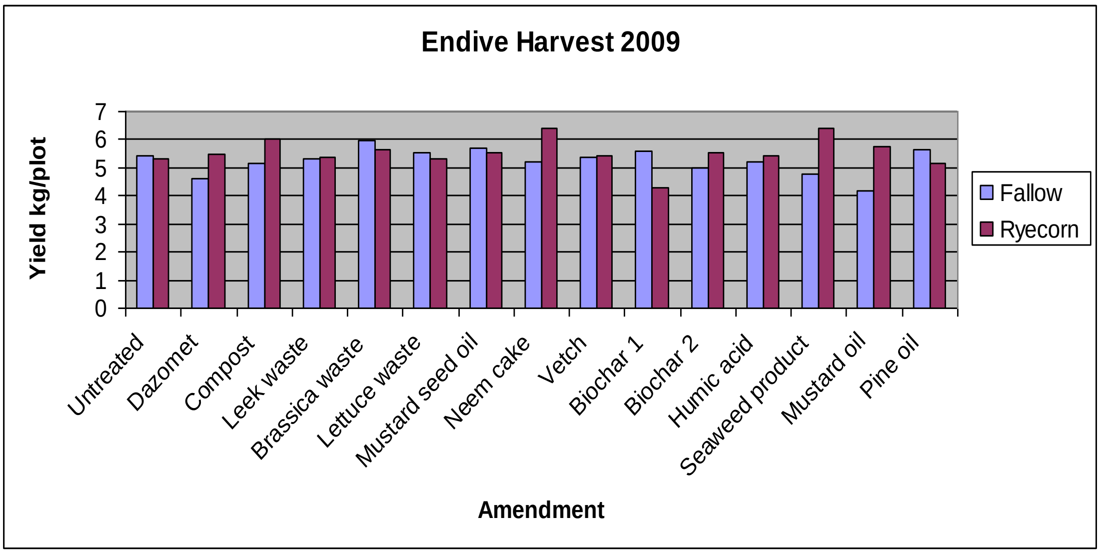


Figure 6.32 The effects of different organic amendments and other treatments on the yield of endive at Devon Meadows in 2009.

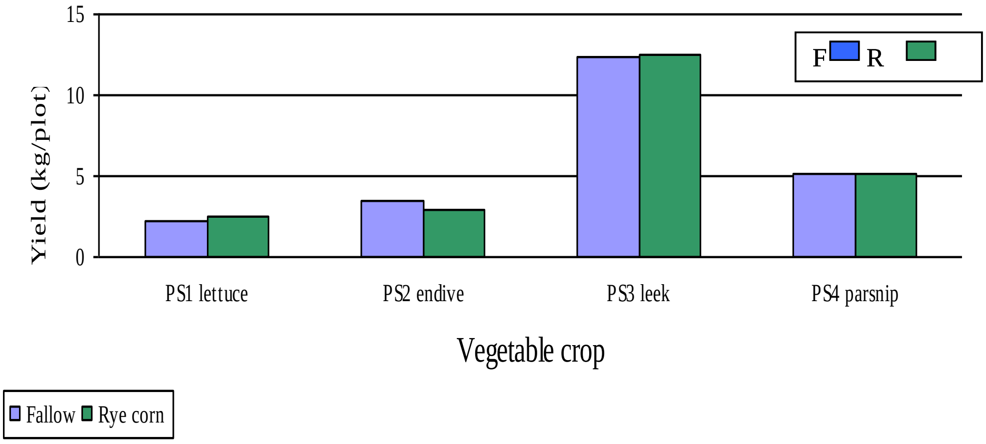


Figure 6.33 The effects of rye corn (R) rotations and fallow (F) on crop yields when evaluated across all four crop rotations and all treatments (2008 -2010).

6.7 Disease incidence

The effect of the carbon and biofumigant amendments on disease incidence was assessed over four consecutive field seasons on the four crops. Disease incidence was low for the first three crops with no differences between treatments. There was a significant reduction in disease, however, in the 4^{th} crop, parsnips, (Figure 6.34). In particular there was a significant decrease in disease incidence for Voom®, the lettuce green waste and the mustardmeal treatments. Further studies are required to confirm this effect, but it is possible that Voom® and mustardmeal had a significant biofumigant effect, while the lettuce green waste may have improved disease suppressiveness.

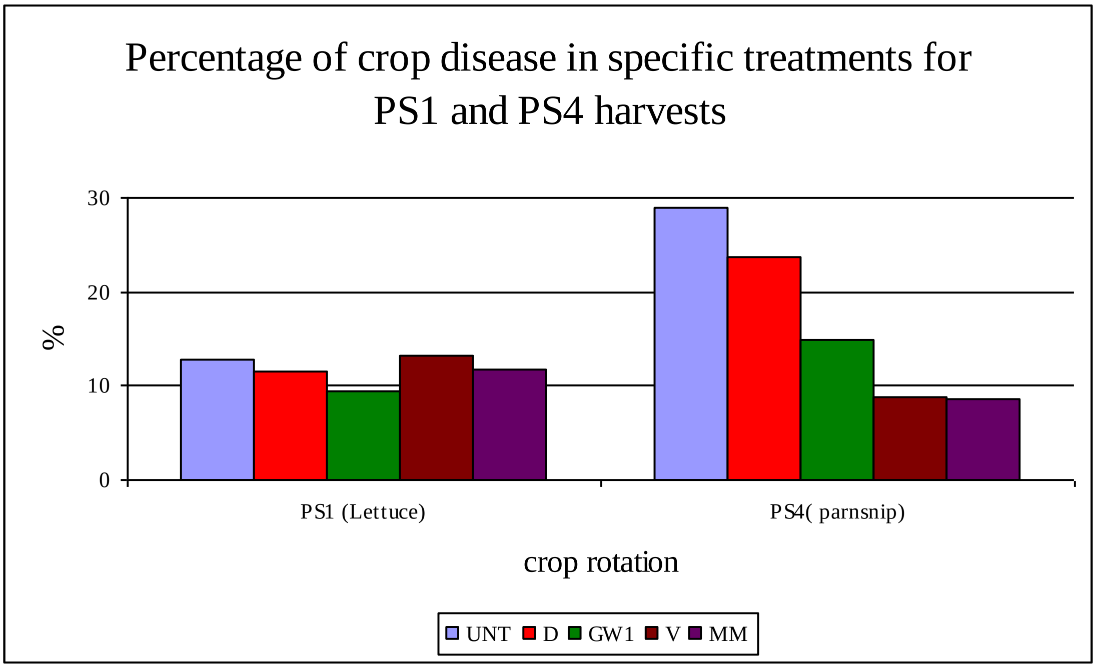


Figure 6.34 Disease incidence in the lettuce (PS1) and parsnip (PS4) crops. UNT=untreated, GW1=green waste (lettuce), V=vetch green manure, MM=mustard meal

6.8 Biological effects

The amendments significantly affected soil microbial communities over the four crop rotations.

6.8.1 Nematodes

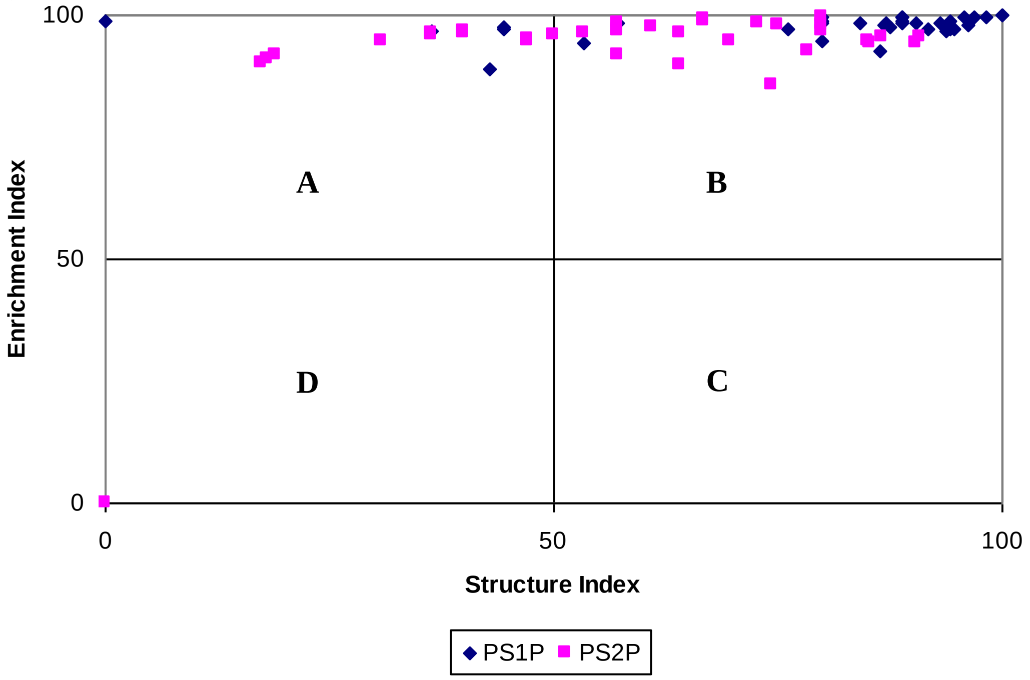
Nematode quadrat analysis (EI/SI) did not separate the sub plot treatments, but there was a significant difference in the indices between planting and harvest. All treatments had very high enrichment indices (EI) (over 90%) which suggests that there are a lot of available nutrients in the soil and consequently a lot of opportunistic nematodes dominating the soil food web community. The channel index (CI) was significant for the rye corn (0.72) rotation compared to fallow for the first crop harvest of lettuce (PS1). The SI was lower at planting than at harvest. At planting, there was a highly N-enriched profile, with high bacterial decomposition, low C:N ratio and a disturbed food web which reflects the tillage and fertilizer applications at planting (quadrat A) (Figure 6.35 a. At harvest, structure index had increased indicating a maturing food web (Figure 6.35 b)

The green waste treatments (GW1 and GW2) with rye corn at planting and harvest had the highest diversity. The treatment with the lowest diversity was the fumigant treatment (Dazomet) following fallow. There was also a reduction of total free living nematodes in all crops and stages with the fumigant treatment. The biofumigant mustard oil (MO) killed all nematodes.

The channel index for all samples was very high suggesting the soils have a fungal dominated decomposition of nutrients. This was supported by the bacterial/fungal ratios of all samples indicating a fungal dominated decomposition (Figure 6.36).

The soils in general tended to have low diversity, high enrichment and low channel indices. This indicates that the treatments were being superimposed on disrupted soils.

a)



b)

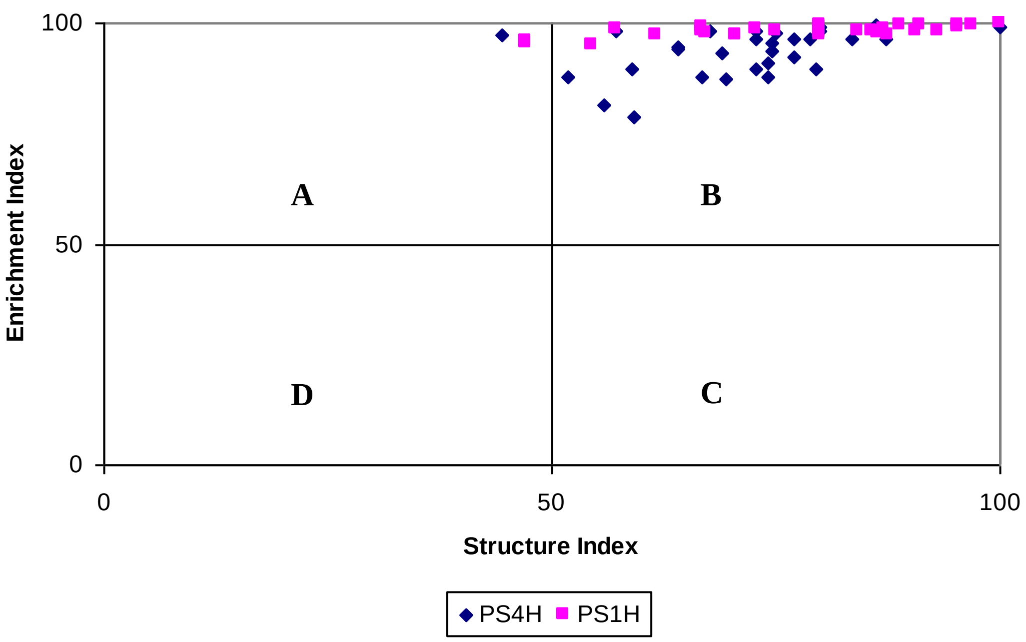


Figure 6.35 Bidimensional space (EI/SI) at planting a) and harvest b) for the soil food web. Soil food web conditions States: Disturbed (quadrat A), Maturing (quadrat B), Structured (quadrat C), Degraded (quadrat D).

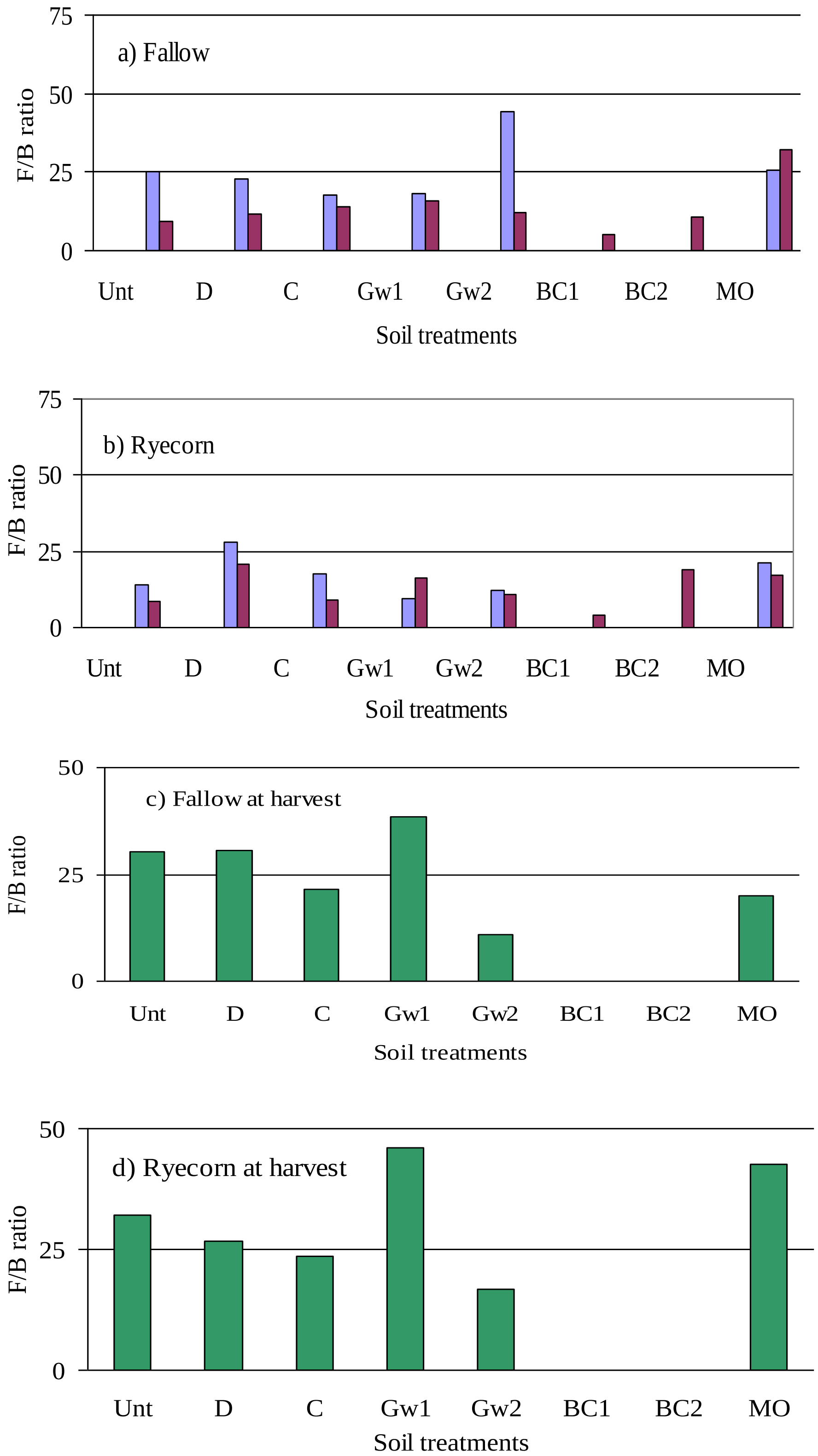


Figure 6.36 Effect of treatments on the fungal feeding nematodes vs. bacterial feeder nematodes (F/B) at different crop stage: Planting a) fallow b) in rye corn and Harvest c) fallow and d) rye corn (Data are the mean of 6 replicates).

PS1P (30/06/2008) PS2P (09/12/2008) PS1H 802/09/200

6.9 Trends in microbial activity

Significant changes in microbial activity, measured by FDA activity, were observed between main plot treatments (rye corn vs. fallow) in all crops and also at crop stage. There were significant differences in size of the microbial population, with rye corn increasing activity compared with fallow at planting and harvest of the first crop (lettuce) and subsequently for all other crops (Figure 6.37). Microbial activity was always higher in the rye corn treatment than the fallow at all crop stages. The microbial activity also increased between planting and harvest (Figure 6.37).

FDA activity was generally increased by the application of carbon amendments relative to the standard grower practice, with compost resulting in the largest increase. After the first harvest, all treatments with rye corn as the split plot treatment had higher microbial activity (Figure 6.38). As expected, the fumigant treatment (Dazomet) had the lowest microbial activity (Figure 6.37).

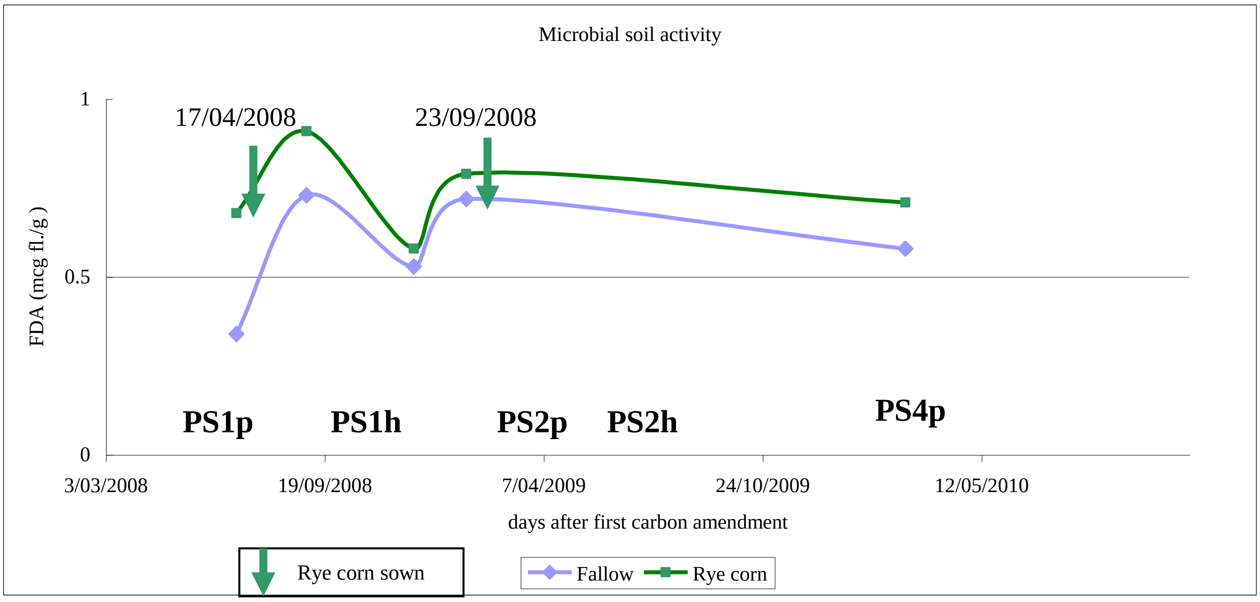


Figure 6.37 Evolution of soil microbial activity FDA (µg fl/g dry soil) on time. There was no significant interaction between sub plot treatments (soil amendments), so data from each was pooled and analysed. Data are the mean of 24 replicates.

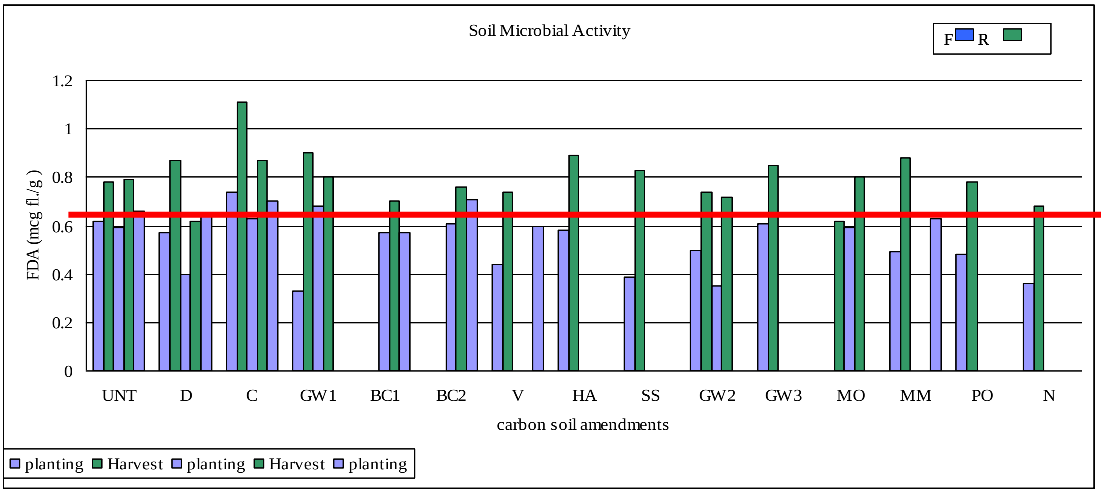


Figure 6.38 Effect on soil microbial activity of different soil amendments at planting and harvest for the four different crops rotation. There were no significant interactions between sub plot treatments, so data (6 reps) was pooled and analysed.

6.10 Chemical effects

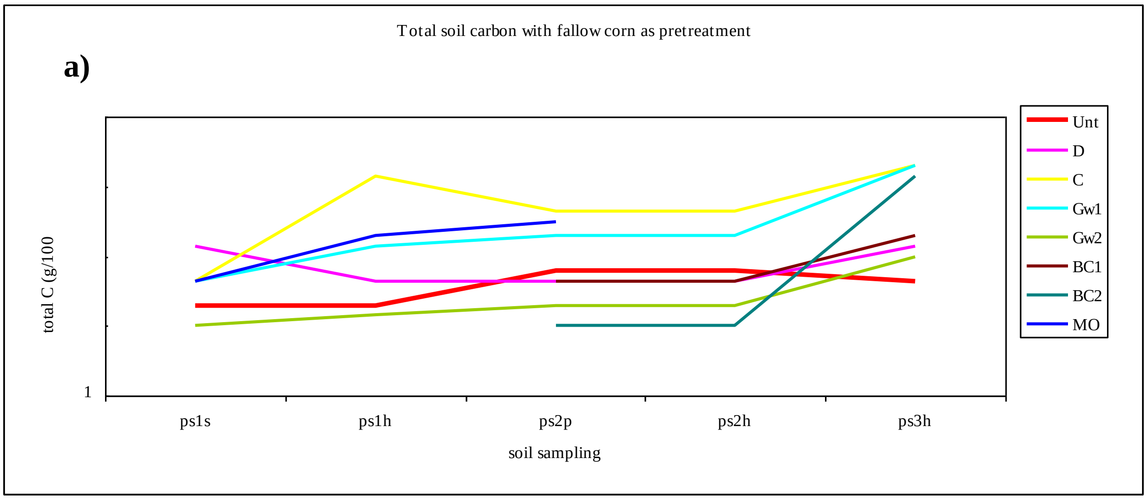
6.10.1 Soil carbon

The majority of nutrients in the soil are tied up in complex organic forms within soil organic matter (SOM), and require mineralisation into inorganic forms to become available to the plant. As microorganisms break down organic matter, nutrients are released from their organic form, becoming soluble or available to the plant. Decomposition of SOM is essential for the recycling of plant nutrients.

The four measures of soil carbon measured in the trial were: total carbon, total organic matter, oxidizable carbon and oxidizable organic matter. All carbon measurements were very highly correlated, so only total carbon is discussed here.

There were no significant differences in total carbon between the main plot treatments of fallow and rye corn (Figure 6.39 a, Figure 6.39 b). The only organic amendment that tended to increase labile carbon consistently across both main plot treatments over the four sowings was compost. At the end of the trial there was also a significant increase of soil carbon by GW1, BC2 and compost.

There was a significant increase in the labile carbon with rye corn (516 mg/kg) compared with fallow (477 mg/Kg).



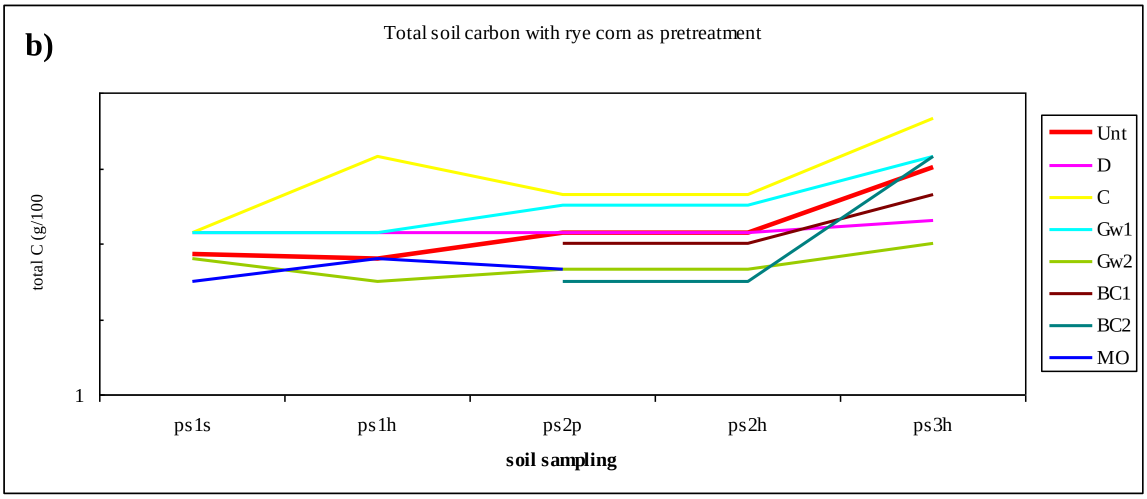


Figure 6.39 Total soil carbon over the four rotation crops (2008-2010) with <u>a) fallow</u> and <u>b) rye corn</u> as a split plot treatment. Data are the mean of 6 replicates. There is no significant interaction between split plot treatments/ treatments factors, so data from each was pooled and analysed.

6.10.2 Soil pH, Total Soluble Salts and Electrical Conductivity

Prior to treatments, the mean soil pH (water) was 6.85 ± 0.28. The soil pH remained in an acceptable range (6.63-7.46) for all treatments for the four crops that were grown during the trial. BC2 treatment increased pH by 0.5 when sown on rye corn plots (Table 6.25).

Electrical conductivity (EC) and total soluble salts (TSS) were highly correlated with each other and with pH, and there were no significant differences between treatments for either property.

Table 6.25 Maximum and minimum level of pH water

Sampling time	Minimum		Maximum	
PS1P	GW1+F	6.86	MO+F	7.40
PS1H	D+Rc	6.96	C+F	7.30
PS2P	D+V	6.96	BC2+Rc	7.46
PS2H	C+F	6.83	BC2+Rc	7.23
PS3H	GW1+Rc	7.03	BC2+Rc	7.40

6.10.3 Soil Nitrogen

Total organic nitrogen (TON) is a measure of the nitrogen contained within SOM. In the current study, changes in TON followed a very similar trend to changes in TOC. Total organic nitrogen was very low (0.11 ± 0.01 g/100g soil) and there were no significant differences between treatments.

Available nitrogen levels tended to be higher at planting than at harvest (Table 6.26).

Table 6.26 Mean available Nitrogen as (NH_4^+ and NO_3^-) at planting and harvest.

Available nitrogen	Nitrate (NO_3^-)	Ammonium (NH_4^+)
planting	29.76 a	1.06 a
harvest	20.76 b	0.54 b
lsd	4.15	0.11

6.10.4 Macronutrients (S, P, K)

Available phosphorous (Olsen) was significantly different between treatments in the three trials and ranged from 75 to 165 mg/kg soil (Table 6.27).

Table 6.27 Treatments with the maximum and minimum level of phosphorus at harvest and planting.

Sampling time	Minimum		Maximum	
PS1P	GW2+F	88.0	C+Rc	103.0
PS1H	D+F	88.0	GW2+F	165.7
PS2P	GW1+Rc	90.7	BC2+F	115.7
PS2H	MO+F	73.7	BC2+F	86.3
PS3H	GW1+Rc	75.0	GW1+F C+F	93.0

The addition of organic amendments did not increase the available potassium or sulphur.

6.10.5 Calcium:Magnesium ratio (Ca/Mg)

There was a significant trend of increasing Ca:Mg ratio with amendments compared to the untreated control at planting for the first crop (Figure 6.40). However, the treatment effect on Ca:Mg ratio was not consistent between crops.

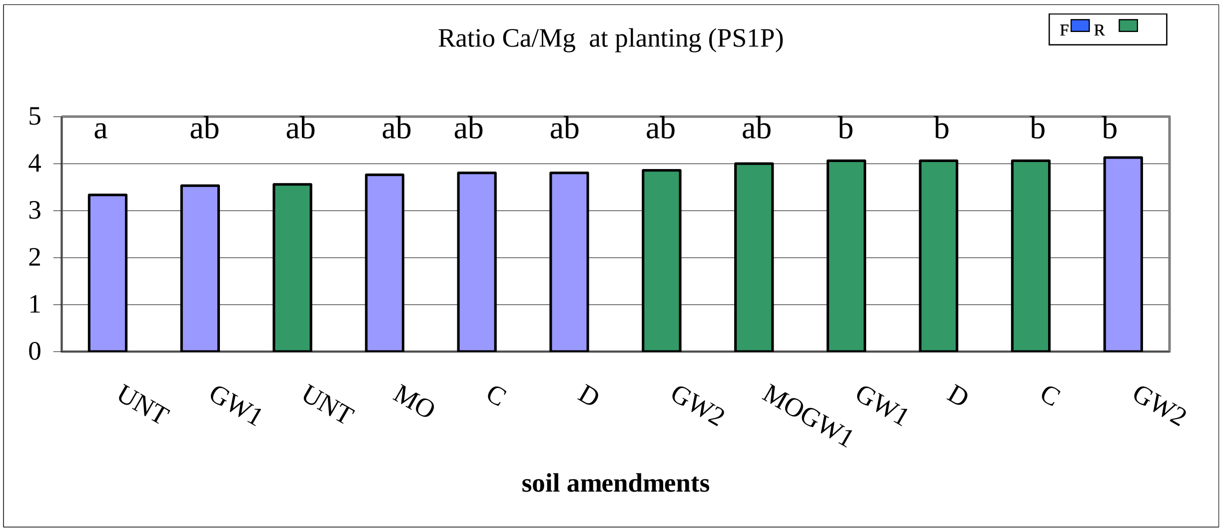


Figure 6.40 Ca/Mg ratio at planting for soil treatments. Data were analysed using analysis of variance. Means were compared by LSD. Different letters after average value mean significant differences at P<0.05. Comparisons are among treatments within the same sampling data. Data are the mean of 6 replicates.

6.11 Conclusions

1) There were increased yields in the first crop (lettuce), from ryecorn plus high organic matter inputs (either biofumigants or high carbon organic matter) which increased organic carbon and led to increased microbial activity.

2) After the first crop, no treatment provided a consistent yield response for the following 3 crops compared with the control.

3) There was a reduction in the disease level with the biofumigants, Voom® and Mustardmeal, and the lettuce green waste in the first crop (lettuce/*pythium* spp).

4) Tillage at planting reduced the EI/SI ratio as determined by nematode measurements, whereas the rye corn application increased soil biodiversity (microbial activity and CI) compared with the fallow.

5) All green waste amendments added to soils where ryecorn had been incorporated had high labile carbon and microbial activity together with a higher nematode diversity index. The leek green waste (GW2) increased the Ca:Mg ratio and available phosphorous significantly compared to the untreated soils. Lettuce green waste increased the concentration of the micronutrient copper (Cu).

6) Green waste compost was one of the few treatments to increase total carbon, and this was reflected with an increase in microbial respiration measured by CO_2 output over 14 days. Compost also increased the Ca/Mg ratio across main plot treatments. The combination of compost with rye corn had a significant effect on the increased availability of micronutrients Fe, Cu and Zn level at the end of the experiment compared to the control.

7) Biochar together with rye corn increased soil pH by more than 0.5 and phosphorous availability but had no other significant effects.

In contrast to the trial at Boneo, there was little response from a range of organic products except the initial yield response that occurred from use of ryecorn as a rotation/mulch crop. This is not unexpected as the history of the farm includes regular crop rotations and this has undoubtedly maintained a reasonable level of diversity in microbial populations and soil nutrition and added to the resilience and soil health of the site. The results also indicate that most nutrients are within thresholds for good crop growth and that changes from addition of organic amendment are only transient as the resident organisms can digest the material very effectively. If future trials are conducted on this site it is recommended that fewer treatments are applied in larger quantities on larger areas.

6.12 Data Appendices

Appendix 6.1. Costs of products applied in field trials.

Product	Cost
Compost (Pinegrow)	$30/m^3$
Nitrabor ($CaNO_3$ + B)	$20.80/25 kg
Calcium nitrate	$20.00/25 kg
Rustica Gold Plus	$48.00/40 kg
Metham sodium	$1.73/ l
Shirlan	$160/l
Lime (GBA)	$261/t
Alzon	$1200/t
Fumafert	$1500/ha
Voom	$1500/ha
Perlka	$1350/t
Chicken manure	$12/m^3$
Silage	$50/t

Appendix 6.2. Soil parameters at Transplanting in trial ST1 (Nitrogen trial)

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Urea	0.730	0.0597	1.367	411	0.707	1.333	7.233	7.667	0.197	0.0633
Alzon®	0.680	0.0563	1.233	357	0.697	1.300	7.167	7.567	0.240	0.0833
Perlka	0.700	0.0473	1.300	368	0.717	1.333	7.267	7.667	0.230	0.0767
$CaNO_3$	0.613	0.0357	1.123	342	0.610	1.133	7.200	7.663	0.223	0.0767
LSD 5%	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.3. Nutrients at Transplanting in trial ST1 (Nitrogen trial)

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Urea	4.07	44.7	98.3	247	14.00	2.500	22.33	3.67	6.233	4.90	0.627	0.1800	<LOD	5.73	7.80	85.33	11.00	3.00	<1
Alzon®	2.47	56.0	102.0	260	13.33	2.533	22.33	4.00	6.500	4.77	0.637	0.1967	<LOD	5.60	7.47	84.67	11.33	3.33	<1
Perlka	3.30	55.7	95.0	230	15.00	2.400	20.67	4.00	6.333	5.30	0.640	0.1867	<LOD	6.13	8.43	86.00	10.33	3.33	<1
$CaNO_3$	2.38	59.7	95.0	240	12.67	2.400	20.33	3.00	6.133	4.50	0.513	0.1700	<LOD	5.20	8.77	86.00	9.67	3.00	<1
LSD 5%	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	-

ns = not significantly different at the 5% level

Appendix 6.4. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Transplanting in trial ST1 (Nitrogen trial)

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Urea	90.3	4.62	0.000044	0.00	-	95.3	0.9510	1.29	13.3	98.57	0.733	514	1129
Alzon®	89.3	2.53	0.000190	0.00	-	93.7	0.9722	0.75	44.4	97.89	0.663	536	1096
Perlka®	81.8	2.32	0.000116	0.00	-	85.2	0.9728	0.71	41.3	98.91	0.748	380	840
$CaNO_3$	74.8	5.35	0.000217	1.06	-	83.4	0.9344	1.81	53.2	96.72	0.754	317	651
LSD 5%	9.21	n.s	n.s	n.s		8.21	n.s	n.s	n.s	n.s	n.s	n.s	n.s

ns = not significantly different at the 5% level

Appendix 6.5. Soil parameters at Harvest in trial ST1 (Nitrogen trial)

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Urea	0.803	0.0797	1.500	297.8	0.853	1.600	7.50	7.93	0.1200	0.0400
Alzon®	0.713	0.0677	1.333	333.3	0.733	1.333	7.50	7.97	0.1133	0.0400
Perlka®	0.747	0.0670	1.367	332.6	0.800	1.500	7.57	8.10	0.1233	0.0433
$CaNO_3$	0.723	0.0680	1.367	327.6	0.880	1.467	7.6	8.13	0.1133	0.0367
LSD 5%	n.s	0.00774	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

ns = not significantly different at the 5% level

Appendix 6.6. Nutrients at Harvest in in trial ST1 (Nitrogen trial)

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Urea	1.200	10.10	106.7	63.0	4.67	2.767	15.67	3.33	6.533	5.333	0.637	0.0777	0.0640	6.133	8.43	87.33	10.33	1.333	0.833
Alzon®	1.233	7.50	92.0	66.7	3.67	2.733	15.33	3.33	6.300	5.100	0.533	0.0730	0.0607	5.767	9.73	88.33	9.00	1.000	1.000
Perlka®	1.233	8.50	92.7	59.7	6.00	2.900	16.00	3.67	6.833	5.900	0.587	0.0683	0.0593	6.600	10.23	89.00	8.67	0.833	0.500
$CaNO_3$	1.033	7.53	88.0	57.7	3.67	2.700	13.67	3.00	6.100	5.167	0.523	0.0667	0.0593	5.800	9.97	89.00	9.00	1.000	0.833
LSD 5%	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	0.5582	0.0791	n.s	n.s	0.5844	n.s	0.881	1.104	n.s	n.s

ns = not significantly different at the 5% level

Appendix 6.7. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in trial ST1 (Nitrogen trial)

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Urea	80.4	8.5	11.1	0.00	-	97.68	0.903	3.71	65.0	89.61	0.550	302	562
Alzon®	80.5	7.3	12.1	0.00	-	95.50	0.915	2.92	74.3	92.79	0.222	350	618
Perlka®	83.7	5.7	10.7	0.00	-	94.27	0.937	2.08	70.6	93.08	0.301	261	462
$CaNO_3$	74.2	12.4	13.0	0.51	-	97.62	0.852	5.48	68.0	88.90	0.261	254	448
LSD 5%	n.s	n.s	n.s	n.s		n.s	n.s		n.s	n.s	n.s	n.s	n.s

ns = not significantly different at the 5% level

Appendix 6.8. Soil parameters at transplanting in short term trial ST2

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.57	<0.05	1.05	274	0.64	1.20	7.50	7.80	0.19	0.06
Lime	0.60	<0.05	1.13	324	0.65	1.20	7.80	8.07	0.19	0.07
Lime/$CaNO_3$/Fluaz	0.61	<0.05	1.13	301	0.72	1.37	7.87	8.20	0.20	0.06
Fluazinam	0.62	<0.05	1.17	306	0.68	1.23	7.33	7.60	0.19	0.07
Metham 850	0.61	<0.05	1.16	312	0.61	1.14	7.44	7.68	0.20	0.07
Perlka®	0.58	<0.05	1.10	293	0.64	1.17	7.97	8.30	0.15	0.05
Compost	0.63	<0.05	1.17	323	0.69	1.27	7.27	7.53	0.19	0.07
Fumafert®	0.57	<0.05	1.06	306	0.64	1.19	7.49	7.78	0.20	0.07
Voom®	0.61	<0.05	1.17	290	0.68	1.27	7.37	7.67	0.19	0.06
Alzon®	0.57	<0.05	1.05	303	0.65	1.23	7.33	7.60	0.22	0.08
LSD 5%	ns	-	ns	ns	ns	ns	0.33	0.381	ns	ns

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.9. Nutrients at transplanting in short term trial ST2

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	1.17	45.3	91.7	196.7	14.0	2.40	15.0	4.00	5.40	4.77	0.59	0.19	<0.05	5.57	8.10	85.3	10.33	3.33	<1
Lime	0.50	46.0	88.7	170.0	10.0	2.27	14.3	2.00	5.47	6.30	0.82	0.18	<0.05	7.30	7.73	86.0	11.33	2.33	<1
Lime/$CaNO_3$/Fluaz	0.67	44.7	89.3	190.0	12.0	2.33	14.7	2.33	5.60	6.27	0.82	0.18	<0.05	7.30	7.70	86.0	11.33	3.67	<1
Fluazinam	0.87	44.0	90.7	183.3	12.3	2.37	16.3	3.00	5.73	4.53	0.56	0.18	<0.05	5.33	8.20	86.0	10.33	3.33	<1
Metham 850	0.98	49.4	87.3	180.2	13.3	2.33	15.4	3.00	5.52	4.66	0.53	0.16	<0.05	5.35	8.56	86.2	10.23	3.06	<1
Perlka®	13.33	10.4	95.7	153.3	12.0	2.17	16.0	5.00	5.37	6.10	0.55	0.17	<0.05	6.83	10.90	88.3	8.33	2.33	<1
Compost	1.17	52.3	87.0	206.7	10.0	2.30	16.7	3.33	5.80	4.53	0.60	0.21	<0.05	5.37	7.73	84.7	11.00	4.00	<1
Fumafert®	0.73	54.9	83.8	180.2	11.29	2.23	13.9	3.00	5.22	4.76	0.54	0.17	<0.05	5.45	8.76	86.7	10.23	3.06	<1
Voom®	0.87	43.3	86.0	173.3	13.0	2.33	14.7	3.00	5.57	4.57	0.55	0.17	<0.05	5.30	8.30	86.0	10.33	3.00	<1
Alzon®	4.00	53.0	93.7	243.3	22.0	2.50	16.3	6.33	5.63	4.70	0.56	0.22	<0.05	5.50	8.47	85.3	10.33	4.00	<1
LSD 5%	3.60	18.54	ns	42.29	ns	ns	ns	ns	ns	ns	0.224	0.031	-	ns	1.244	1.56	1.231	0.94	-

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.10. Biology - Nematode parameters and FDA hydrolysis at transplanting in short term trial ST2

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg CO_2/g soil)	CO_2 14 d (µg CO_2/g soil)
Untreated	92.1	4.3	3.6	0.00	0.96	-	2.29	43.7	85.0	0.89	108	397
Lime	89.9	5.2	4.9	0.00	0.95	-	3.03	43.3	81.4	0.98	83	347
Lime/$CaNO_3$/Fluaz	-	-	-	-	-	-	-	-	-	1.00	82	303
Fluazinam	-	-	-	-	-	-	-	-	-	0.75	82	336
Metham 850	100	0.0	0.2	0.05	1.00	-	-0.29	17.7	93.4	1.18	125	466
Perlka®	98.2	1.1	0.3	0.34	0.99	-	0.35	16.1	88.9	0.21	72	264
Compost	92.3	3.2	4.6	0.00	0.97	-	1.31	28.7	91.3	0.69	103	383
Fumafert®	95.1	2.1	2.8	0.00	0.98	-	0.75	36.8	90.3	1.87	-	-
Voom®	96.3	1.8	2.0	0.00	0.98	-	0.57	33.0	93.7	0.96	113	376
Alzon®	95.2	3.0	1.8	0.00	0.97	-	1.07	44.7	93.2	1.14	112	440
LSD 5%	ns	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	ns

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.11. Soil parameters at Harvest in short term trial ST2

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.73	<LOD	1.37	337	0.77	1.43	7.47	7.97	0.097	0.030
Lime	0.74	0.023	1.37	303	0.78	1.44	7.90	8.39	0.108	0.034
Lime/$CaNO_3$/Fluaz	0.75	0.017	1.40	389	0.76	1.40	7.87	8.37	0.100	0.033
Fluazinam	0.72	<LOD	1.30	371	0.78	1.43	7.43	8.03	0.083	0.030
Metham 850	0.72	<LOD	1.33	325	0.77	1.67	7.53	8.10	0.090	0.030
Perlka®	0.70	<LOD	1.30	371	0.78	1.40	7.57	8.07	0.113	0.037
Compost	0.90	0.026	1.60	411	0.94	1.70	7.30	7.80	0.097	0.030
Fumafert®	0.76	0.017	1.40	364	0.80	1.47	7.43	7.97	0.103	0.030
Voom®	0.78	0.021	1.43	419	0.80	1.47	7.30	7.83	0.110	0.037
Alzon®	0.70	<LOD	1.3	381	0.74	1.37	7.23	7.77	0.120	0.043
LSD 5%	ns	ns	ns	ns	ns	ns	0.28	0.329	ns	ns

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.12. Nutrients at Harvest in short term trial ST2

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	0.73	7.6	90.7	75.3	2.00	2.50	15.7	2.00	6.10	4.83	0.66	0.097	<0.05	5.63	7.23	85.7	12.0	1.7	<1
Lime	0.50	15.2	107.7	67.1	2.54	2.65	14.9	1.98	6.27	7.50	0.75	0.074	<0.05	8.29	9.79	89.6	9.0	0.7	<1
Lime/$CaNO_3$/Fluaz	0.50	11.8	103.3	78.7	3.67	2.93	15.3	2.00	6.60	7.43	0.73	0.087	<0.05	8.27	10.20	89.7	8.7	0.8	<1
Fluazinam	0.50	7.4	92.0	69.3	1.00	2.73	15.0	2.00	6.43	4.47	0.60	0.088	<0.05	5.2	7.40	86.0	11.7	2.0	<1
Metham 850	0.50	7.9	90.3	72.7	1.67	2.90	14.7	2.33	6.40	4.80	0.60	0.086	<0.05	5.53	8.10	86.7	10.7	1.3	<1
Perlka®	0.73	19.7	104.3	76.0	5.00	2.80	14.0	3.00	6.90	6.13	0.55	0.096	<0.05	6.83	11.00	90.0	8.3	1.3	<1
Compost	0.87	11.6	82.0	77.3	1.67	2.90	18.3	2.67	7.27	4.63	0.67	0.102	<0.05	5.4	6.90	85.3	12.3	2.0	<1
Fumafert®	0.60	10.8	85.3	63.7	3.00	2.83	14.67	2.67	6.67	4.90	0.61	0.086	<0.05	5.63	8.07	87.0	11.0	1.3	<1
Voom®	0.67	15.4	115.7	70.3	3.00	3.17	14.67	3.00	7.70	4.67	0.65	0.091	<0.05	5.43	7.33	86.0	11.7	2.0	<1
Alzon®	0.93	21.7	96.3	86.7	3.33	2.90	15.0	2.67	6.47	4.43	0.51	0.105	<0.05	5.07	9.10	87.7	9.7	2.0	<1
LSD 5%	0.28	17.65	22.66	ns	ns	0.261	2.236	ns	ns	0.954	ns	ns	-	1.062	1.361	1.415	1.439	0.697	-

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.13. Biology - Nematode parameters and FDA hydrolysis at harvest in short term trial ST2

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated	38.9	37.3	21.6	2.2	0.51	1.96	29.2	66.5	72.6	-	343	639
Lime	35.0	23.9	37.9	3.2	0.60	1.92	22.0	84.2	76.5	-	370	708
Lime/CaNO_3/Fluaz	50.4	29.0	19.1	1.6	0.63	1.87	23.0	64.3	73.5	-	352	651
Fluazinam	38.0	30.3	28.6	3.1	0.56	1.86	25.1	73.5	73.9	-	305	595
Metham 850	75.8	8.8	13.2	2.3	0.88	0.94	3.6	67.4	94.9	-	360	598
Perlka®	56.8	23.9	18.2	1.1	0.71	1.65	14.5	65.1	79.4	-	367	686
Compost	40.4	26.7	30.2	2.8	0.61	1.79	20.1	75.6	77.1	-	485	845
Fumafert®	58.1	16.3	24.2	1.4	0.79	1.55	8.1	76.7	87.6	-	347	656
Voom®	52.9	32.2	11.4	3.6	0.60	1.54	19.6	57.8	81.5	-	481	865
Alzon®	48.5	38.6	12.9	0.0	0.55	1.67	21.2	50.2	78.6	-	289	526
LSD 5%	ns	ns	ns	ns	ns	0.444	ns	ns	9.67	-	110	ns

Fluaz = fluazinam, ns = not significantly different at the 5% level

Appendix 6.14. Soil parameters at transplanting in short term trial ST3

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.843	0.046	1.567	302.0	0.873	1.633	7.433	7.933	0.2133	0.0733
Standard practice	0.783	0.056	1.433	298.3	0.867	1.633	7.367	7.767	0.3367	0.1167
Lime	0.803	0.045	1.467	318.7	0.907	1.700	7.900	8.467	0.1967	0.0667
Chicken manure	0.950	0.064	1.800	305.3	0.997	1.833	7.233	7.767	0.2467	0.0800
Metham 850	0.797	0.052	1.467	302.0	0.850	1.567	7.500	8.033	0.2200	0.0733
Alzon®	0.793	0.055	1.467	293.7	0.900	1.667	7.100	7.567	0.2433	0.0833
Compost	1.056	0.066	1.958	362.5	1.100	2.056	7.322	7.831	0.2761	0.0947
Fumafert®	-	-	-	-	-	-	-	-	-	-
Voom®	-	-	-	-	-	-	-	-	-	-
Perlka®	-	-	-	-	-	-	-	-	-	-
LSD 5%	0.1392	n.s	0.299	n.s	0.1344	0.2402	0.2651	0.2968	0.05508	0.02135

ns = not significantly different at the 5% level

Appendix 6.15. Nutrients at transplanting in short term trial ST3

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	0.47	45.7	120.0	173.3	10.33	2.567	16.67	3.000	6.267	5.467	0.703	0.157	<LOD	6.37	7.80	86.33	11.33	2.33	<1
Standard practice	2.88	143.3	116.7	140.0	10.00	2.467	14.00	3.000	6.033	5.70	0.543	0.120	<LOD	6.37	11.03	89.33	8.33	2.00	<1
Lime	2.17	39.7	116.7	170.0	10.67	2.467	16.67	3.000	6.000	6.033	0.980	0.160	<LOD	7.23	6.13	83.67	13.67	2.00	<1
Chicken manure	1.85	62.3	136.7	226.7	13.67	2.867	15.00	4.333	6.800	5.333	0.780	0.210	<LOD	6.37	6.97	84.00	12.00	3.33	<1
Metham 850	0.51	49.3	123.3	180.0	13.00	2.533	16.00	3.333	6.333	5.767	0.790	0.183	<LOD	6.77	7.37	85.33	11.67	2.67	<1
Alzon®	0.35	78.7	120.0	163.3	11.33	2.633	16.00	3.667	6.367	5.133	0.620	0.147	<LOD	5.90	8.33	87.00	10.33	2.33	<1
Compost	1.01	51.2	127.2	220.6	13.58	2.714	21.31	3.972	7.275	5.622	0.875	0.231	<LOD	6.75	6.43	82.78	12.56	3.03	<1
Fumafert®																			
Voom®																			
Perlka®																			
LSD 5%	ns	18.33	ns	ns	ns	0.2075	1.824	0.7470	0.4985	ns	0.225	0.0545	-	ns	1.963	2.81	2.276	0.868	-

ns = not significantly different at the 5% level

Appendix 6.16. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at transplanting in short term trial ST3

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated	58.0	10.7	23.2	0.0	0.840	91.9	5.73	80.56	89.6	0.670	273	566
Standard practice	59.5	8.3	17.8	0.0	0.878	85.7	4.33	81.45	91.9	0.629	225	469
Lime	44.0	18.7	28.9	0.0	0.704	91.7	12.53	81.05	84.1	0.776	221	510
Chicken manure	55.1	6.8	31.4	0.6	0.862	93.8	5.97	89.17	88.3	1.377	525	1244
Metham 850	44.9	11.0	32.7	0.0	0.804	88.6	6.96	87.77	89.6	0.854	277	525
Alzon®	61.7	7.6	24.9	0.0	0.890	94.3	3.60	87.62	93.9	1.025	269	525
Compost	60.9	14.7	18.7	0.0	0.806	94.3	6.97	74.98	89.1	0.915	334	720
Fumafert®	-	-	-	-	-	-	-	-	-	0.953	-	-
Voom®	-	-	-	-	-	-	-	-	-	0.990	-	-
Perlka®	-	-	-	-	-	-	-	-	-	1.133	-	-
LSD 5%	ns	6.201	ns	ns	0.1071	ns	4.955	6.532	ns	0.3637	ns	ns

ns = not significantly different at the 5% level

Appendix 6.17. Soil parameters at Harvest in short term trial ST3

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.733	0.0250	1.333	251	0.830	1.533	7.233	7.900	0.0800	0.0267
Standard practice	0.743	0.0250	1.367	266	0.790	1.467	7.233	7.833	0.0933	0.0333
Lime	0.797	0.0333	1.467	290	0.847	1.600	7.667	8.300	0.0900	0.0300
Chicken manure	0.950	0.0547	1.733	330	1.000	1.900	7.033	7.500	0.1167	0.0400
Metham 850	0.780	0.0333	1.433	302	0.857	1.567	7.233	7.800	0.0833	0.0300
Alzon®	0.797	0.0337	1.500	291	0.883	1.633	7.167	7.700	0.0833	0.0300
Compost	0.997	0.0587	1.800	300	1.057	1.967	7.167	7.733	0.0833	0.0300
Fumafert®	0.800	0.0340	1.467	258	0.863	1.567	7.133	7.633	0.0967	0.0333
Voom®	0.777	0.0343	1.433	292	0.857	1.600	7.233	7.800	0.0833	0.0300
Perlka®	0.750	0.0250	1.400	272	0.803	1.467	7.400	7.933	0.0833	0.0300
LSD 5%	0.1209	0.01883	0.2323	ns	0.1475	0.2708	0.1480	0.1627	ns	ns

ns = not significantly different at the 5% level

Appendix 6.18. Nutrients at Harvest in short term trial ST3

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	1.37	5.9	113.3	81.7	<LOD	3.00	17.33	3.333	6.433	5.133	0.593	0.0867	<LOD	5.833	8.63	88.33	10.33	1.333	<1
Standard practice	0.35	17.1	105.3	76.7	<LOD	2.833	16.67	3.000	6.333	5.367	0.580	0.0857	<LOD	6.067	9.27	88.67	9.67	1.000	<1
Lime	0.35	10.6	106.3	84.7	<LOD	2.833	16.33	3.000	6.067	6.700	0.960	0.0843	<LOD	7.733	6.97	86.33	12.33	0.833	<1
Chicken manure	0.87	24.5	126.7	92.3	<LOD	3.000	17.00	4.000	7.000	5.567	0.610	0.0860	<LOD	6.267	9.17	88.67	9.67	1.333	<1
Metham 850	2.27	6.4	110.0	74.0	<LOD	2.967	17.33	3.333	6.700	5.800	0.653	0.0847	<LOD	6.533	8.83	88.33	10.00	1.000	<1
Alzon®	0.35	6.8	106.7	83.7	<LOD	2.933	18.67	3.000	6.500	5.800	0.567	0.0863	<LOD	6.100	9.63	89.00	9.33	1.333	<1
Compost	4.03	5.4	110.0	98.7	<LOD	2.900	21.67	3.667	7.033	5.300	0.670	0.1100	<LOD	6.133	7.90	87.00	11.00	2.000	<1
Fumafert®	1.62	18.6	110.0	70.3	<LOD	2.867	16.67	3.333	6.467	5.400	0.510	0.0677	<LOD	6.000	10.60	90.33	8.33	0.833	<1
Voom®	0.85	7.7	113.3	75.7	<LOD	2.967	17.67	3.667	6.600	5.300	0.587	0.0777	<LOD	6.000	9.03	88.67	9.67	1.000	<1
Perlka®	3.57	6.7	113.3	70.3	<LOD	2.833	18.00	3.667	6.233	5.533	0.583	0.0720	<LOD	6.200	9.50	89.00	9.33	0.833	<1
LSD 5%	ns	ns	ns	ns	-	ns	1.163	0.5997	0.5746	0.486	0.085	0.0202	-	0.5411	1.31	1.637	1.333	0.6198	-

ns = not significantly different at the 5% level

Appendix 6.19. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in short term trial ST3

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated	53.2	9.76	30.0	0.00	0.845	92.97	6.59	82.9	86.02	0.770	276.7	540
Standard practice	47.5	12.39	29.0	0.50	0.793	89.37	10.93	76.8	77.18	0.603	276.6	533
Lime	46.1	13.23	33.5	0.55	0.776	93.47	9.63	83.8	83.90	0.792	284.0	521
Chicken manure	54.8	12.61	26.5	1.13	0.794	95.06	8.17	79.3	86.86	1.038	432.3	959
Metham 850	28.6	16.50	39.1	0.00	0.632	84.12	15.47	87.2	82.67	0.590	302.6	555
Alzon®	52.5	14.68	25.8	0.00	0.782	89.68	9.94	75.9	81.91	0.799	291.5	592
Compost	43.0	23.43	30.3	0.00	0.650	96.66	20.94	76.4	73.96	0.944	310.0	696
Fumafert®	43.7	10.62	27.4	1.09	0.794	82.74	9.30	81.6	82.70	0.963	317.4	610
Voom®	35.0	10.86	44.0	0.51	0.746	90.15	14.57	85.5	72.66	1.032	328.5	647
Perlka®	42.0	13.38	36.6	1.01	0.760	93.26	11.36	84.2	80.63	1.141	261.8	525
LSD 5%	ns	ns	ns	ns	ns	8.505	7.952	ns	8.527	0.3375	61.19	120

ns = not significantly different at the 5% level

Appendix 6.20. Soil parameters at Transplanting in short term trial ST4

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.810	0.0660	1.500	378.2	0.903	1.667	7.300	7.700	0.1533	0.050
Standard practice	0.780	0.0643	1.467	364.8	0.890	1.667	7.267	7.700	0.1567	0.050
Lime	0.833	0.0673	1.533	375.0	0.870	1.600	7.367	7.833	0.1533	0.050
Chicken manure	0.867	0.0743	1.600	394.2	0.907	1.667	7.200	7.533	0.1767	0.060
Metham 850	0.793	0.0620	1.467	406.2	0.837	1.567	7.533	7.967	0.1567	0.053
Alzon®	0.907	0.0733	1.667	368.2	0.920	1.733	7.167	7.567	0.1700	0.057
Compost	0.870	0.0713	1.600	386.6	0.937	1.733	7.267	7.700	0.1633	0.053
Fumafert®	0.803	0.0690	1.500	378.2	0.873	1.633	7.100	7.467	0.1833	0.060
Voom®	0.857	0.0673	1.600	374.8	0.890	1.633	7.300	7.767	0.1467	0.050
Perlka®	0.780	0.0657	1.467	357.5	0.863	1.600	7.233	7.700	0.1833	0.060
LSD 5%	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.21. Nutrients at Transplanting in short term trial ST4

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	0.917	27.7	146.7	163.3	8.67	3.067	15.00	4.00	6.03	4.733	0.593	0.1467	<LOD	5.53	8.00	85.67	11.00	2.667	<1
Standard practice	1.117	33.0	140.0	140.0	7.33	3.000	14.67	3.67	6.03	4.700	0.563	0.1267	<LOD	5.47	8.40	87.00	10.00	2.333	<1
Lime	0.883	26.7	140.0	153.3	8.00	2.933	15.00	3.67	5.93	4.933	0.603	0.1400	<LOD	5.73	8.13	86.00	10.33	2.667	<1
Chicken manure	1.317	44.0	146.7	166.7	9.67	3.067	15.00	4.00	6.17	4.700	0.593	0.1433	<LOD	5.43	7.93	85.67	11.00	2.667	<1
Metham 850	0.750	30.0	146.7	153.3	8.00	2.933	15.00	3.33	5.87	5.467	0.690	0.1400	<LOD	6.30	8.00	86.33	10.67	2.333	<1
Alzon®	0.783	40.7	140.0	133.3	9.33	3.000	14.67	4.00	5.97	4.567	0.537	0.1133	<LOD	5.23	8.47	86.67	10.33	2.333	<1
Compost	1.350	35.0	146.7	186.7	11.67	2.967	16.67	4.00	6.47	4.700	0.670	0.1700	<LOD	5.60	7.17	84.33	12.00	3.000	<1
Fumafert®	1.683	53.0	143.3	160.0	9.00	3.167	15.33	4.33	6.03	4.633	0.543	0.1300	<LOD	5.37	8.57	86.67	10.00	2.333	<1
Voom®	1.067	24.3	143.3	156.7	7.00	2.967	14.67	4.00	5.83	4.767	0.580	0.1333	<LOD	5.53	8.27	86.33	10.67	2.333	<1
Perlka®	1.417	50.0	143.3	146.7	7.33	2.967	14.67	4.00	5.87	5.000	0.527	0.1300	<LOD	5.67	9.37	87.67	9.67	2.333	<1
LSD 5%	ns	14.76	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	ns	0.967	1.641	ns	ns	-

ns = not significantly different at the 5% level

Appendix 6.22. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Transplanting in short term trial ST4

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN (%)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated	71.3	11.49	8.1	0.00	0.8610	90.88	5.60	49.8	85.9	0.640	272.9	521
Standard practice	60.7	18.95	11.0	0.00	0.7645	90.64	10.14	53.8	82.4	0.489	261.8	477
Lime	58.1	11.32	20.6	0.00	0.8395	89.98	8.79	66.3	75.2	0.487	328.6	636
Chicken manure	55.8	12.44	28.7	0.00	0.8154	96.96	9.45	76.4	79.3	0.841	339.7	673
Metham 850	49.1	13.04	32.5	0.62	0.7877	95.33	14.09	75.9	68.9	0.574	302.6	581
Alzon®	54.6	15.10	19.6	0.00	0.7829	89.31	11.06	65.9	78.1	0.523	261.8	477
Compost	40.8	15.31	33.1	0.00	0.7279	89.23	15.03	79.6	75.5	0.591	354.5	718
Fumafert®	59.6	15.03	16.9	0.00	0.7940	91.55	9.79	68.1	83.0	0.620	295.2	529
Voom®	55.9	8.07	27.3	0.56	0.8740	91.84	5.71	80.8	83.4	0.459	183.9	214
Perlka®	50.9	11.07	26.7	0.61	0.8234	89.30	10.69	74.0	72.1	0.674	265.5	488
LSD 5%	12.16	ns	9.47	ns	ns	ns	5.310	12.86	ns	ns	89.30	232

ns = not significantly different at the 5% level

Appendix 6.23. Soil parameters at Harvest in short term trial ST4

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Untreated	0.873	0.0640	1.633	371.8	0.89	1.63	7.600	8.067	0.1633	0.0533
Standard practice	0.847	0.0633	1.567	391.9	0.92	1.73	7.567	8.033	0.1933	0.0667
Lime	0.797	0.0607	1.467	386.0	0.83	1.53	7.567	8.033	0.1767	0.0600
Chicken manure	0.863	0.0700	1.600	395.3	0.90	1.67	7.433	7.900	0.1767	0.0567
Metham 850	0.753	0.0573	1.400	382.8	0.82	1.50	7.533	8.033	0.1767	0.0600
Alzon®	0.737	0.0543	1.367	415.5	0.80	1.50	7.467	8.000	0.1600	0.0533
Compost	0.980	0.0733	1.833	393.2	0.97	1.80	7.467	8.000	0.1600	0.0567
Fumafert®	0.793	0.0587	1.467	410.8	0.88	1.63	7.400	7.867	0.1667	0.0533
Voom®	0.760	0.0550	1.400	371.9	0.87	1.57	7.567	8.067	0.1433	0.0500
Perlka®	0.793	0.0607	1.467	373.0	0.81	1.53	7.600	8.033	0.1700	0.0567
LSD 5%	0.1067	0.0072	0.2360	ns	ns	ns	ns	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.24. Nutrients at Harvest in short term trial ST4

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Untreated	0.700	6.20	150.0	111.0	13.00	3.53	16.33	3.33	6.70	5.033	0.663	0.127	0.107	5.93	7.60	84.67	11.00	2.00	1.67
Standard practice	0.600	7.23	150.0	123.3	18.33	3.43	16.33	3.33	6.73	5.100	0.670	0.147	0.127	6.03	7.67	84.67	10.67	2.33	2.00
Lime	0.567	5.60	146.7	116.7	13.67	3.67	16.00	3.37	6.67	5.433	0.687	03140	0.120	6.37	7.97	85.00	10.33	2.33	1.67
Chicken manure	0.633	9.60	143.3	108.0	13.67	3.37	16.33	3.67	6.80	5.000	0.670	0.123	0.118	5.87	7.40	84.67	11.67	2.00	1.67
Metham 850	0.600	8.10	143.3	120.0	16.67	3.30	15.67	3.33	6.50	4.967	0.633	0.143	0.114	5.83	7.87	84.67	10.67	2.33	1.67
Alzon®	0.633	6.07	143.3	102.7	12.67	3.20	15.67	3.00	6.40	5.033	0.643	0.106	0.077	5.87	7.80	85.67	11.00	2.00	1.00
Compost	0.700	5.00	146.7	110.0	13.33	3.27	17.33	3.33	6.60	5.033	0.673	0.120	0.074	5.93	7.50	85.33	11.33	2.00	1.00
Fumafert®	0.667	7.47	146.7	104.0	12.67	3.33	16.33	3.33	6.53	4.967	0.647	0.107	0.071	5.80	7.63	86.00	11.00	2.00	1.00
Voom®	0.567	4.93	146.7	95.3	9.67	3.33	15.67	3.00	6.20	5.167	0.670	0.103	0.068	6.00	7.73	86.00	11.00	2.00	1.00
Perlka®	0.950	7.83	143.3	105.3	13.33	3.30	16.67	3.33	6.57	5.533	0.660	0.110	0.077	6.40	8.50	86.67	10.67	2.00	0.83
LSD 5%	ns	2.80	ns	ns	4.135	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.25. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in short term trial ST4

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	B/(B+F)	TFLN	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated	32.6	8.20	19.1	0.00	0.8193	59.9	11.09	78.2	76.7	0.555	321.1	566
Standard practice	35.6	8.07	19.2	0.00	0.8105	62.9	8.90	77.6	80.9	0.553	291.5	507
Lime	31.4	7.85	20.0	0.00	0.7958	59.2	10.91	78.3	76.3	0.513	313.7	544
Chicken manure	47.0	15.42	19.0	0.00	0.7564	81.5	11.36	69.6	81.2	0.736	365.6	647
Metham 850	51.1	11.31	21.1	0.00	0.8175	83.5	10.29	70.6	76.2	0.358	328.5	573
Alzon®	50.3	9.45	25.7	3.34	0.8429	88.8	10.25	76.2	72.0	0.469	328.6	573
Compost	52.0	11.97	22.9	2.27	0.8160	89.2	13.67	70.1	66.9	0.487	332.2	621
Fumafert®	42.6	10.30	35.1	0.61	0.8054	88.7	19.24	78.1	57.5	0.512	336.0	584
Voom®	46.4	12.08	31.1	0.00	0.7927	89.5	12.89	77.5	72.6	0.475	354.5	614
Perlka®	46.8	11.38	29.0	0.00	0.8027	87.2	13.8	74.6	67.6	0.678	336.0	603
LSD 5%	13.47	ns	10.68	2.014	ns	19.44	ns	ns	12.61	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.26. Soil parameters at Transplanting in long term trial LTY1

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice	0.627	0.043	1.167	317.7	0.633	1.167	7.3	7.733	0.183	0.06
Metham sodium	0.603	0.025	1.113	309.3	0.607	1.133	7.3	7.733	0.190	0.0633
Compost	1.333	0.1097	2.433	421.7	1.167	2.167	7	7.433	0.320	0.1100
Chicken manure	1.107	0.0810	2.067	416.7	1.087	2.00	7.43	8.000	0.393	0.133
Silage	0.713	0.0550	1.333	323.3	0.713	1.33	7.3	7.767	0.213	0.07
LSD 5%	0.3225	0.0259	0.5943	28.03	0.241	0.378	0.1702	0.27	0.0779	0.027

ns = not significantly different at the 5% level

Appendix 6.27. Nutrients at Transplanting in long term trial LTY1

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice	5.33	42.7	89.0	207	10.67	2.300	22.3	2.67	5.9	4.767	0.647	0.180	0.025	5.63	7.43	85.0	11.33	3.33	0.5
Metham sodium	4.67	41.3	90.3	223	14.33	2.233	20.7	2.33	5.6	4.767	0.587	0.183	0.025	5.60	8.17	85.3	10.33	3.33	0.5
Compost	6.20	84.0	98.0	383	20.33	2.533	30.0	4.00	8.1	4.667	0.947	0.317	0.025	6.00	4.93	78.3	15.67	5.33	0.5
Chicken manure	34.67	25.4	140.0	610	42.33	3.767	40.3	19.67	8.2	4.967	0.933	0.507	0.0767	6.53	5.27	76.7	14.33	7.67	0.833
Silage	4.13	35.7	100.3	270	12.33	2.367	21.0	3.67	5.9	4.633	0.650	0.213	0.025	5.53	7.13	83.7	12.0	3.67	0.5
LSD 5%	3.743	27.33	13.98	89.1	7.198	0.385	8.09	2.077	0.72	ns	0.1053	0.0867	0.0175	0.69	0.944	2.215	1.417	1.396	0.243

ns = not significantly different at the 5% level

Appendix 6.28. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Transplanting in long term trial LTY1

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Standard practice	89.4	5.86	4.75	0	17.0	-	0.938	1.7	61.7	97.28	0.48	362	751
Metham sodium	91.05	6.44	2.52	0	9.2	-	0.934	1.76	57.1	97.97	0.49	303	599
Compost	95.77	3.06	1.17	0	6.8	-	0.969	0.82	20.5	98.40	1.36	421	881
Chicken manure	98.06	3.94	0.00	0	0	-	0.961	1.05	0.00	98.74	3.32	1878	7188
Silage	96.49	2.89	0.62	0	3.5	-	0.971	0.75	26.7	99.07	1.59	492	1044
LSD 5%	ns	ns	ns	-	ns	-	ns	ns	ns	ns	0.738	489.1	1556.4

ns = not significantly different at the 5% level

Appendix 6.29. Soil parameters at Harvest in long term trial LTY1

Treatment (Fertilizer rate %)	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice (100)	0.707	0.0697	1.300	305.7	0.723	1.333	7.633	8.133	0.1067	0.0333
Standard practice (50)	0.900	0.0840	1.667	293.5	0.887	1.633	7.633	8.067	0.1167	0.0400
Metham sodium (100)	0.657	0.0630	1.233	278.6	0.700	1.300	7.567	8.033	0.1333	0.0467
Metham sodium (50)	0.630	0.0610	1.167	316.7	0.680	1.267	7.600	8.100	0.1067	0.0367
Compost (100)	1.267	0.1230	2.400	365.5	1.267	2.367	7.367	7.833	0.1367	0.0467
Compost (50)	1.400	0.1327	2.567	431.0	1.327	2.467	7.400	7.900	0.1400	0.0433
Chicken manure (100)	1.167	0.1200	2.167	414.9	1.093	2.000	7.100	7.467	0.1900	0.0633
Chicken manure (50)	1.467	0.1467	2.733	506.1	1.433	2.633	7.033	7.400	0.2167	0.0733
Silage (100)	0.833	0.0823	1.533	290.6	0.877	1.633	7.500	7.933	0.1333	0.0433
Silage (50)	0.813	0.0777	1.467	330.5	0.810	1.500	7.467	7.933	0.1333	0.0433
LSD 5%	0.4391	0.03964	0.7855	76.23	0.3951	0.6987	0.1172	0.1473	0.03841	0.01353

Appendix 6.30. Nutrients at Harvest in long term trial LTY1

Treatment (Fertilizer rate %)	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice (100)	1.10	6.7	97.0	62.0	3.33	2.50	13.00	2.67	5.20	4.967	0.487	0.073	0.062	5.600	10.47	89.0	8.67	0.073	1.0
Standard practice (50)	1.20	7.0	92.3	64.7	5.33	2.50	13.67	3.00	5.53	4.933	0.583	0.080	0.064	5.667	8.60	87.3	10.33	0.080	1.0
Metham sodium (100)	1.00	16.5	89.0	56.3	5.00	2.50	13.67	3.00	5.43	5.100	0.460	0.069	0.061	5.667	11.00	89.7	8.00	0.069	1.0
Metham sodium (50)	1.20	7.0	91.0	60.3	5.33	2.53	13.00	2.67	5.47	4.967	0.537	0.075	0.065	5.600	6.27	88.0	9.33	0.075	1.0
Compost (100)	2.47	10.5	109.0	136.7	4.33	2.57	21.33	3.67	8.00	5.167	0.957	0.183	0.076	6.400	5.40	81.0	15.00	0.183	1.0
Compost (50)	2.17	7.4	96.7	143.3	4.67	2.70	22.33	3.67	8.03	5.333	1.037	0.207	0.088	6.667	5.20	80.0	15.33	0.207	1.3
Chicken manure (100)	3.67	30.3	183.3	84.7	6.33	3.27	13.00	6.00	9.13	5.667	0.977	0.101	0.069	6.833	5.80	83.0	14.33	0.101	1.0
Chicken manure (50)	4.20	31.0	236.7	136.3	6.33	3.57	16.00	7.67	10.17	6.100	1.367	0.157	0.075	7.767	4.50	79.0	17.67	0.157	0.7
Silage (100)	1.37	14.1	99.0	66.0	4.67	2.53	14.00	3.67	5.90	4.967	0.557	0.087	0.067	5.700	8.93	87.3	9.67	0.087	1.0
Silage (50)	1.37	11.7	103.7	64.7	3.67	2.60	14.00	3.67	5.90	4.967	0.617	0.893	0.072	5.767	8.20	86.3	10.67	0.893	1.0
LSD 5%	0.684	10.59	45.53	36.20	1.41	0.37	2.973	1.491	0.984	0.5690	0.223	0.040	0.011	0.716	1.485	2.105	2.397	0.040	ns

ns = not significantly different at the 5% level

Appendix 6.31. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in long term trial TLY1

Treatment (Fertilizer rate %)	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Untreated (100)	81.9	7.4	10.72	0.00	0.00	0.917	2.83	70.2	91.5	0.143	169	344
Untreated (50)	76.6	11.4	10.24	1.76	0.00	0.872	5.02	63.8	88.3	0.092	261	455
Standard practice (100)	87.8	3.6	8.00	0.68	0.00	0.960	1.14	73.9	96.1	0.310	280	507
Standard practice (50)	80.2	7.0	12.80	0.00	1.74	0.919	2.91	69.4	90.9	0.168	215	410
Compost (100)	75.9	13.4	10.73	0.00	0.00	0.849	6.22	63.8	88.9	0.303	446	896
Compost (50)	67.4	22.0	10.56	0.00	0.62	0.754	11.02	64.1	84.5	0.296	457	933
Chicken manure (100)	78.3	11.2	10.48	0.00	1.50	0.867	12.44	38.6	55.4	1.277	696	1204
Chicken manure (50)	65.2	28.5	5.75	0.55	0.00	0.695	21.67	26.1	65.2	1.426	780	1438
Silage (100)	88.0	3.7	8.30	0.00	0.69	0.960	1.47	55.2	90.0	0.336	351	633
Silage (50)	73.0	13.3	13.68	0.00	0.00	0.840	6.79	53.9	81.6	0.218	321	577
LSD 5%	ns	7.38	n.s	n.s	n.s	0.3138	6.628	27.13	9.85	0.2585	162.8	302.4

ns = not significantly different at the 5% level

Appendix 6.32. Soil parameters at Transplanting in long term trial LTY2

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice	0.83	0.07	1.53	295.7	0.82	1.53	7.63	8.10	0.19	0.06
Metham sodium	0.81	0.07	1.50	304.3	0.80	1.47	7.67	8.10	0.20	0.07
Compost	1.33	0.11	2.47	365.7	1.23	2.30	7.33	7.73	0.26	0.09
Chicken manure	1.08	0.10	1.97	342.3	1.07	2.03	7.20	7.53	0.36	0.12
Silage	0.98	0.09	1.80	310.3	0.96	1.77	7.77	8.33	0.34	0.12
Lignite – High rate	1.11	0.07	2.07	335.3	1.07	2.03	7.27	7.63	0.19	0.07
LSD 5%	0.3277	0.02106	0.5731	31.04	0.2763	0.2457	0.1135	0.0858	0.0829	0.01297

Appendix 6.33. Nutrients at Transplanting in long term trial LTY2

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice	0.35	25.7	116.7	173.3	7.7	2.4	16.7	2.0	6.5	4.73	0.62	0.15	0.05	5.57	7.70	85.33	11.00	3.00	0.67
Metham sodium	1.40	27.3	104.7	193.3	8.0	2.4	16.0	2.3	6.3	4.90	0.61	0.17	0.05	5.73	7.93	85.33	11.00	3.00	0.67
Compost	1.67	60.7	130.0	296.7	11.7	2.5	21.3	3.0	7.8	4.80	0.75	0.23	0.06	5.80	6.37	82.00	13.00	4.00	0.83
Chicken manure	3.63	83.3	146.7	343.3	25.0	2.7	18.3	5.3	7.9	5.20	0.86	0.25	0.06	6.40	6.13	81.67	13.67	4.00	0.67
Silage	1.17	20.3	116.7	440.0	12.0	2.4	18.0	4.7	6.5	5.07	0.77	0.39	0.09	6.30	6.60	80.33	12.00	6.00	1.00
Lignite – High rate	0.35	25.7	126.7	176.7	9.7	2.6	17.3	3.7	7.0	5.00	0.71	0.17	0.06	5.93	7.03	84.33	11.67	3.00	0.67
LSD 5%	ns	14.35	16.63	96.6	9.61	ns	1.68	1.85	0.68	ns	0.077	0.053	0.016	0.316	0.851	2.463	1.315	0.996	ns

ns = not significantly different at the 5% level

Appendix 6.34. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Transplanting in long term trial LTY2

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Standard practice	74.19	11.13	13.91	0.67	-	99.4	0.87	5.09	65.87	91.06	0.537	262	521
Metham sodium	85.02	6.87	8.12	0.00	-	100.0	0.93	2.30	67.85	94.42	0.650	329	710
Compost	85.41	8.80	5.76	0.00	-	100.0	0.91	2.81	61.39	95.25	0.750	336	755
Chicken manure	82.80	7.40	9.79	0.00	-	100.0	0.92	2.74	63.73	92.62	1.184	1415	3195
Silage	91.27	4.70	4.03	0.00	-	100.0	0.95	1.43	51.55	95.88	1.282	573	1185
Lignite – High rate	84.00	8.01	8.00	0.00	-	100.0	0.91	3.01	59.85	92.75	0.602	269	551
LSD 5%	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	0.4278	ns	ns

ns = not significantly different at the 5% level

Appendix 6.35. Soil parameters at Harvest in long term trial LTY2

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice	0.843	0.0447	1.567	301.3	0.860	1.600	7.267	7.767	0.0833	0.0300
Metham sodium	0.827	0.0367	1.533	307.0	0.907	1.667	7.167	7.633	0.0800	0.0300
Compost	1.147	0.0730	2.100	335.3	1.197	2.233	7.100	7.533	0.0900	0.0300
Chicken manure	0.960	0.0640	1.800	347.0	1.067	1.967	6.933	7.333	0.1067	0.0367
Silage	0.873	0.0480	1.633	333.0	0.947	1.733	7.200	7.600	0.1033	0.0333
Lignite – High rate	0.927	0.0333	1.733	357.7	1.067	2.000	7.100	7.500	0.0867	0.0300
LSD 5%	ns	ns	ns	ns	0.2161	ns	0.1033	0.1135	0.00939	ns

ns = not significantly different at the 5% level

Appendix 6.36. Nutrients at Harvest in long term trial LTY2

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice	0.65	8.73	123.3	66.3	1.50	3.167	18.67	3.67	6.60	5.867	0.617	0.0723	<LOD	6.567	9.50	89.00	9.33	0.833	<1
Metham sodium	1.12	7.03	126.7	78.0	1.50	3.333	19.67	4.00	6.67	5.467	0.553	0.0773	<LOD	6.100	9.87	89.33	9.00	1.000	<1
Compost	1.17	8.20	126.7	111.7	2.00	3.233	23.67	4.67	7.70	5.500	0.680	0.1163	<LOD	6.300	8.17	87.33	10.67	1.667	<1
Chicken manure	1.83	15.33	143.3	90.0	1.50	3.433	19.67	5.33	8.20	5.567	0.657	0.0910	<LOD	6.300	8.47	88.00	10.33	1.333	<1
Silage	0.68	13.00	133.3	120.0	2.00	3.300	21.00	5.33	7.10	5.767	0.640	0.1267	<LOD	6.533	9.00	88.00	9.67	2.000	<1
Lignite – High rate	0.35	8.63	123.3	76.0	2.00	3.400	20.33	4.67	7.30	5.467	0.593	0.0707	<LOD	6.133	9.20	88.67	9.67	1.167	<1
LSD 5%	ns	4.177	13.15	30.36	ns	ns	2.508	1.085	0.865	ns	ns	ns	-	ns	ns	ns	ns	0.6643	-

ns = not significantly different at the 5% level

Appendix 6.37. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in long term trial LTY2

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Standard practice	71.31	4.18	21.60	2.86	-	92.12	0.95	1.76	81.98	92.68	0.526	277	525
Metham sodium	57.67	7.36	34.87	0.00	-	97.62	0.89	3.61	86.64	91.91	0.539	310	581
Compost	65.63	7.22	27.15	0.00	-	98.64	0.90	3.17	83.26	93.19	0.611	380	770
Chicken manure	67.65	7.65	24.74	0.00	-	98.79	0.90	4.07	72.58	84.99	1.170	432	870
Silage	53.84	6.77	38.21	1.21	-	98.15	0.88	4.82	82.18	86.01	0.796	406	777
Lignite – High rate	49.58	9.50	40.30	0.55	-	96.11	0.83	6.81	86.01	86.69	0.458	303	584
LSD 5%	n.s	n.s	n.s	1.927	-	n.s	n.s	2.640	n.s	6.150	0.3424	n.s	232.9

ns = not significantly different at the 5% level

Appendix 6.38. Soil parameters at Transplanting in long term trial LTY3

Treatment	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice	0.80	0.07	1.47	-	0.86	1.60	7.23	7.67	0.16	0.05
Metham sodium	0.75	0.06	1.40	-	0.82	1.53	7.23	7.67	0.14	0.05
Compost	1.01	0.09	1.87	-	1.04	1.93	7.07	7.43	0.25	0.08
Chicken manure	0.86	0.08	1.60	-	0.92	1.70	7.03	7.33	0.26	0.09
Silage	0.90	0.08	1.63	-	0.86	1.60	7.23	7.63	0.22	0.07
Lignite – High rate	1.08	0.08	1.97	-	1.13	2.10	7.13	7.50	0.15	0.05
Lignite – Low rate	0.85	0.07	1.60	-	0.91	1.67	7.20	7.63	0.14	0.05
LSD 5%	ns	ns	ns	-	0.156	0.2781	0.1363	0.122	0.088	0.0311

ns = not significantly different at the 5% level

Appendix 6.39. Nutrients at Transplanting in long term trial LTY3

Treatment	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice	0.467	25.33	146.7	183.3	7.33	2.97	17.33	4.00	6.40	5.20	0.64	0.17	<LOD	6.03	8.10	86.00	10.67	3.00	<1
Metham sodium	0.817	24.33	146.7	170.0	7.67	3.10	16.67	4.00	6.30	4.93	0.58	0.15	<LOD	5.67	8.43	86.33	10.33	3.00	<1
Compost	1.017	58.00	146.7	300.0	17.33	3.07	19.33	4.33	7.83	5.30	0.78	0.26	0.02	6.40	7.10	83.33	12.00	3.67	<1
Chicken manure	1.017	70.00	156.7	306.7	23.67	3.37	17.33	5.33	7.37	4.90	0.63	0.20	<LOD	5.77	7.87	85.00	11.00	3.67	<1
Silage	0.700	41.33	153.3	256.7	9.67	3.00	16.67	4.00	6.70	4.90	0.63	0.21	0.02	5.80	7.87	84.67	10.67	4.00	<1
Lignite – High rate	0.767	27.33	146.7	203.3	7.00	3.07	17.00	4.67	6.70	4.93	0.62	0.17	<LOD	5.77	7.93	85.33	11.00	3.00	<1
Lignite – Low rate	0.767	24.67	146.7	186.7	6.67	3.10	16.67	4.00	6.60	4.97	0.61	0.16	<LOD	5.80	8.23	86.00	10.67	3.00	<1
LSD 5%	ns	29.12	ns	81.31	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significantly different at the 5% level

Appendix 6.40. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Transplanting in long term trial LTY3

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Standard practice	87.2	6.76	6.07	0.00	0	100	0.928	2.47	48.4	91.4	0.799	-	-
Metham sodium	90.0	5.32	3.36	1.31	0	100	0.944	1.94	50.1	93.1	0.763	-	-
Compost	87.9	4.05	8.06	0.00	0	100	0.955	1.55	58.3	92.8	1.030	-	-
Chicken manure	92.6	1.23	6.22	0.00	0	100	0.987	0.43	63.7	94.7	1.148	-	-
Silage	87.7	2.63	9.70	0.00	0	100	0.971	0.89	67.8	95.7	0.871	-	-
Lignite – High rate	83.3	8.24	7.32	0.22	0	99	0.911	3.01	61.3	92.8	0.806	-	-
Lignite – Low rate	83.2	9.06	7.71	0.00	0	100	0.901	3.28	51.9	92.3	0.796	-	-
LSD 5%	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	ns	-	-

ns = not significantly different at the 5% level

Appendix 6.41. Soil parameters at Harvest in long term trial LTY3

Treatment (Fertilizer rate %)	Total Carbon (%)	Total Nitrogen (%)	Organic matter (%)	Labile Carbon (mg/kg)	Oxidizable Carbon (%)	Oxidizable Organic matter (%)	pH $CaCl_2$	pH water	EC (dS/m)	TSS (%)
Standard practice (100)	0.857	0.0667	1.600	-	0.967	1.800	7.467	7.867	0.1967	0.0667
Standard practice (50)	0.843	0.0677	1.567	-	0.920	1.700	7.500	7.900	0.1933	0.0667
Metham sodium (100)	0.847	0.0657	1.567	-	0.847	1.533	7.433	7.833	0.1933	0.0633
Metham sodium (50)	0.820	0.0657	1.533	-	0.910	1.700	7.500	7.967	0.1600	0.0533
Compost (100)	1.090	0.0873	1.967	-	1.130	2.067	7.300	7.700	0.2233	0.0767
Compost (50)	1.190	0.0960	2.133	-	1.167	2.167	7.367	7.767	0.2033	0.0700
Chicken manure (100)	0.977	0.0860	1.833	-	0.973	1.833	6.967	7.300	0.2767	0.0967
Chicken manure (50)	0.957	0.0770	1.767	-	0.927	1.733	7.167	7.500	0.2167	0.0700
Silage (100)	0.970	0.0797	1.800	-	1.020	1.867	7.300	7.733	0.2100	0.0700
Silage (50)	1.037	0.0850	1.867	-	1.017	1.900	7.400	7.800	0.2133	0.0733
Lignite Low rate (100)	1.327	0.0817	2.467	-	1.290	2.367	7.267	7.600	0.2033	0.0667
Lignite High rate (50)	1.147	0.0710	2.133	-	1.120	2.100	7.267	7.667	0.1833	0.0600
Lignite Low rate (100)	0.940	0.687	1.733	-	1.027	1.900	7.333	7.733	0.1867	0.0633
Lignite High rate (50)	1.013	0.0747	1.867	-	0.987	1.867	7.367	7.733	0.1867	0.0633
LSD 5%	0.3395	0.02456	0.6120	-	0.2994	0.5565	0.1902	0.2076	0.05073	0.01852

Appendix 6.42. Nutrients at Harvest in long term trial LTY3

Treatment (Fertilizer rate %)	Available nutrients (mg/kg)					Trace elements (mg/kg)				Cations (meq/100g)						Cations as %			
	NH_4 N	NO_3 N	P	K	S	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	Sum of 4	Ca:Mg	Ca	Mg	K	Na
Standard practice (100)	0.567	28.7	146.7	120.0	13.7	3.30	16.3	3.33	7.267	5.23	0.650	0.104	0.062	6.000	8.00	86.33	10.67	1.667	1.000
Standard practice (50)	0.600	18.0	160.0	123.3	16.0	3.30	17.3	3.33	7.233	5.73	0.730	0.120	0.069	6.633	7.77	85.67	11.00	2.00	0.833
Metham sodium (100)	0.750	35.3	153.3	109.7	14.7	3.37	16.0	3.33	6.867	5.77	0.633	0.103	0.062	6.533	9.27	87.67	9.67	1.667	0.500
Metham sodium (50)	0.633	8.7	160.0	110.0	14.3	3.40	17.3	3.00	6.97	5.40	0.700	0.103	0.070	6.300	7.77	86.33	11.00	2.00	0.833
Compost (100)	1.017	39.0	153.3	180.0	13.7	3.40	20.3	4.00	8.533	5.47	0.803	0.162	0.062	6.467	6.80	84.00	12.67	2.333	0.667
Compost (50)	1.083	21.5	146.7	190.0	15.7	3.37	21.3	4.00	8.833	5.53	0.940	0.193	0.082	6.733	6.10	81.67	13.67	2667	0.833
Chicken manure (100)	1.017	66.7	180.0	153.3	19.3	3.67	17.0	5.00	8.667	5.37	0.690	0.130	0.054	6.233	7.73	85.67	11.33	2.000	0.500
Chicken manure (50)	0.783	31.7	156.7	153.3	16.3	3.60	17.7	4.00	7.967	5.17	0.633	0.143	0.058	6.000	8.13	86.00	10.67	2.333	0.667
Silage (100)	0.917	38.7	160.0	156.7	9.3	3.40	17.7	4.00	7.333	5.33	0.677	0.137	0.061	6.200	7.90	86.00	11.00	2.000	0.667
Silage (50)	0.883	29.6	143.3	153.3	13.0	3.27	18.3	4.33	7.267	5.37	0.753	0.153	0.073	6.367	7.17	84.33	11.67	2.333	1.000
Lignite Low rate (100)	0.633	30.0	136.7	143.3	14.7	3.27	17.7	4.33	7.400	5.33	0.643	0.144	0.092	6.233	8.30	86.00	10.33	2.333	1.333
Lignite High rate (50)	0.533	14.2	143.3	124.0	12.7	3.40	18.0	4.33	7.567	5.40	0.697	0.116	0.070	6.267	7.77	86.33	11.00	1.667	1.000
Lignite Low rate (100)	0.667	26.3	146.7	115.0	11.0	3.37	18.0	4.00	7.400	5.33	0.633	0.116	0.907	6.167	8.40	86.33	10.33	1.667	1.333
Lignite High rate (50)	0.600	15.9	150.0	133.3	13.3	3.40	17.3	4.00	7.500	5.67	0.710	0.130	0.067	6.533	7.97	86.00	11.00	2.000	0.833
LSD 5%	0.421	25.34	18.52	49.98	ns	0.19	2.11	0.66	0.659	ns	0.111	0.048	ns	ns	1.181	2.150	1.737	ns	ns

ns = not significantly different at the 5% level

Appendix 6.43. Biology - Nematode parameters, FDA hydrolysis and microbial respiration at Harvest in long term trial LTY3

Treatment	Bacterial feeders (%)	Fungal feeders (%)	Omnivores (%)	Predatory (%)	Plant parasitic (%)	TFLN (%)	B/(B+F)	Channel Index	Structure Index	Enrichment Index	FDA (mg F/kg soil/h)	CO_2 4 d (µg/CO_2 g soil)	CO_2 14 d (µg/CO_2 g soil)
Standard practice	30.3	8.4	12.4	0.00	48.9	51.1	0.812	11.8	65.9	70.3	1.154	-	-
Metham sodium	51.4	4.2	21.8	0.00	22.6	77.4	0.915	4.0	79.1	84.7	0.848	-	-
Compost	43.5	9.9	20.8	1.65	24.1	75.9	0.816	8.5	76.6	81.1	0.850	-	-
Chicken manure	48.8	12.0	12.1	0.00	27.2	72.8	0.814	8.7	63.8	83.5	0.955	-	-
Silage	44.4	6.1	13.8	0.00	35.7	64.3	0.873	5.4	72.2	84.9	0.857	-	-
Lignite – High rate	34.7	4.2	15.1	0.00	46.0	54.0	0.874	9.7	71.3	73.4	0.567	-	-
Lignite – Low rate	39.6	6.8	8.8	0.00	44.7	54.0	0.860	6.7	59.3	81.4	0.848	-	-
LSD 5%	ns	ns	ns	1.055	18.25	18.25	ns	ns	ns	ns	ns	-	-

ns = not significantly different at the 5% level

Appendix 6.44. Mean celery weight/plant in the crop following trial LTY1

Treatment	high fertilizer	low fertilizer
Standard practice	2.37	2.46
Metham sodium	2.42	2.34
Compost	2.38	2.27
Chicken manure	2.40	2.35
Silage	2.44	2.53
LSD (5%)	ns	ns

ns = not significantly different at the 5% level

Appendix 6.45. Mean celery weight per plant and the incidence of Sclerotinia disease symptoms in the crop following trial LTY2

Treatment	Yield/plant (Kg)	Sclerotina incidence (%)
Standard practice	2.34	50.0
Metham sodium	2.37	32.5
Compost	2.31	50.0
Chicken manure	2.38	65.0
Silage	2.45	50.0
Lignite	2.42	37.5
LSD (5%)	ns	ns

ns = not significantly different at the 5% level

Appendix 6.46. Silverbeet yield in the crop following trial LTY3

Treatment	Yield/6 plants (kg)
Standard practice	4.15
Metham sodium	3.38
Compost	3.92
Chicken manure	3.41
Silage	3.97
Lignite	3.92
LSD (5%)	ns

ns = not significantly different at the 5% level

Appendix 6.47. Long Term Trial No. 2: List of split plot treatments rates and codes. Main plot treatments included rotation with a rye-corn (Rc) green manure crop and fallow (F). Treatment and rates of soil amendments applied over the four crop cycles.

Treatments	**Treatment codes**	**Dose rate**
CONTROLS		
1) Untreated	U	untreated
2) Dazomet (fungicide)	D	400 kg/ha
ORGANIC INPUTS – Solids		
3) Compost	C	10t/ha
4) Green waste (leek)	GW2	5 t/ha
5) Green waste (brassica)	GW3	5 t/ha
6) Green waste (lettuce)	GW1	5 t/ha
7) Vetch green manure crop	V	sowing rate 100 kg/ha
8) Biochar type 1 (parent material: Hard wood chip)	BC1	10 t/ha
9) Biochar type2 (parent material: Chicken manure)	BC2	10 t/ha
ORGANIC INPUTS – Liquids		
10) Humic acid treatment,	HA	5L/ha
11) Seaweed amendment (Seasol)	SS	5L/ ha
BIOFUMIGANTS and Oils		
14) Pine oil (interceptor)	PO	90L/ha as a 10% solution
12) Mustard oil (Vigour)	MO	50 L/ha
13) Mustard seed meal (Fumafert)	MM	2 t/ha
15) Neem cake	N	0.6 t/ha

Appendix 6.48. Long Term Trial No. 2: Field trial plan.

GW1	GW3	SS	MM	UNT	GW2
C	HA	PO	GW3	V	N
BC1	N	UNT	PO	BC1	SS
GW2	V	MO	C	D	BC2
D	MM	BC2	GW1	HA	MO

Block 1

HA	N	C	BC2	GW3	UNT
UNT	SS	GW1	SS	V	GW1
D	GW3	V	N	C	D
GW2	BC2	MO	MM	BC1	HA
BC1	PO	MM	GW2	MO	PO

Block 4

N	C	MO	PO	HA	BC2
D	BC1	UNT	UNT	SS	GW2
HA	BC2	MM	N	C	V
GW2	GW3	V	D	GW3	BC1
SS	GW1	PO	GW1	MO	MM

Block 2

D	MM	UNT	SS	GW1	BC2
C	N	SS	HA	MM	C
HA	BC1	MO	N	PO	V
GW3	BC2	V	GW2	MO	D
GW1	GW2	PO	UNT	GW3	BC1

Block 5

UNT	C	HA	V	GW1	SS
V	GW1	D	D	C	MO
MO	N	GW2	UNT	N	HA
GW3	BC2	SS	BC2	BC1	GW2
BC1	PO	MM	MM	GW3	PO

Block 3

HA	PO	N	SS	GW3	UNT
C	D	UNT	V	BC2	GW1
MO	GW2	GW1	BC1	C	PO
BC2	SS	GW3	MM	GW2	N
MM	V	BC1	MO	D	HA

Block 6

Rye corn (Rc)
(sowing rate 50 kg/ha)
Fallow (F)

Appendix 6.49. Long Term Trial No. 2: Lettuce yields (rotation 1).

PSY1 (lettuce) HARVEST 02/09/2008									
Soil treatments amendments		(Y) Plant production (#plants/plot)		(W)Yield Kg/Plot		(W/Y) lettuce Weight average g/Plant		Increase yield production (Treat-Unt)	
								ΔW=W-Wo	%ΔW= (W-Wo)/Wo
UNT	F	12.66	ab	1.95	ab	127,30	abcd	-	-
	Rc	13.50	ab	2.59	bc	193,50	e	0.64	33.07
D	F	16.50	b	3.08	bc	185,80	cde	1.13	58.03
	Rc	18.33	b	3.45	d	188,70	de	1.50	77.00
C	F	13.5	ab	2.33	abc	145,40	abcde	0.38	19.48
	Rc	17.16	b	3.42	d	196,10	e	1.47	75.72
GW1	F	14.33	ab	2.46	abc	141,30	abcde	0.51	26.23
	Rc	15.50	b	2.74	bc	171,70	bcde	0.79	40.85
BC1	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
BC2	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
V	F	16.33	b	2.39	abc	146,40	abcde	0.44	22.73
	Rc	14.66	b	2.28	abc	129,50		0.33	17.09
HA	F	13.16	ab	1.95	ab	122,20	abc	0.00	0.34
	Rc	14.00	ab	2.26	abc	1360	abcde	0.31	16.06
SS	F	15.33	b	2.78	bc	185,20	cde	0.83	42.82
	Rc	8.66	a	1.33	a	96,80	a	-0.61	-31.36
GW2	F	14.33	ab	1.93	ab	113,80	ab	-0.02	-1.02
	Rc	17.33	b	2.96	bc	171,80	bcde	1.01	52.05
GW3	F	12.66	ab	1.95	ab	127,40	abcd	0.00	0.34
	Rc	15.16	b	2.30	abc	125,70	abcd	0.35	18.03
MO	F	15.66	ab	2.30	abc	147,40	abcde	0.35	18.03
	Rc	12.83	ab	1.97	ab	149,10	abcde	0.02	1.36
MM	v	12.16	ab	2.03	ab	135,90	abcde	0.08	4.35
	V	17.50	b	3.06	bc	175,30	bcde	1.11	56.92
PO	F	13.83	ab	2.10	ab	153,20	abcde	0.15	7.94
	Rc	15.33	b	2.09	ab	134,20	abcde	0.14	7.52
LSD P<0.05		6.38		1.23		6.36			
		sig		sig		sig			

Appendix 6.50. Long Term Trial No. 2: Endive yield (rotation 2).

PSY2 (endive) HARVEST				
Soil treatments amendments		(W)Yield Kg/Plot	Increase yield production (Treat-Unt)	Increase yield production (Treat-Unt) ΔW=W-Wo
			ΔW= (W-Wo)	%ΔW= (W-Wo)/Wo
UNT	F	5,435	0,17	0,00
	Rc	5,3	-1,17	-2,48
D	F	4,52	-0,44	-16,68
	Rc	5,47	0,08	0,67
C	F	6.01	-0,28	-5,13
	Rc	5,15	0,57	10,49
GW1	F	6,00	-0,91	-2,48
	Rc	5,66	0,04	9,75
BC1	F	5,60	-0,14	3,20
	Rc	4,26	0,53	-21,53
BC2	F	4,99	0,23	-8,05
	Rc	5,51	0,10	1,40
V	F	5,37	-0,12	-1,17
	Rc	5,44	-0,09	0,11
HA	F	5,21	-0,22	-4,02
	Rc	5,44	0,01	0,16
SS	F	6.40	0,28	-12,33
	Rc	4,76	0,11	17,66
GW2	F	5,53	-1,26	4,19
	Rc	5,31	0,33	1,79
GW3	F	5,30	-0,25	-2,27
	Rc	5,34	0,94	-1,63
MO	F	4,18	0,19	-23,09
	Rc	5,76	-0,27	6,12
MM	v	5,71	-0,67	5,15
	V	5,54	0,96	2,07
PO	F	5,62	0,00	3,45
	Rc	5,17	-0,14	-4,88
N	F	5,18	-0,06	-4,60
	Rc	6,37	0,01	17,36

Appendix 6.51. Long Term Trial No. 2: Leek yield (rotation 3).

Soil treatments amendments		(Y) Plants production (#plants/plot)		(W)Yield Kg/plot		(W/Y) leek Yield g/Plant		Increase yield production (Treat-Unt)	
								∆W=W-Wo	%∆W= (W-Wo)/Wo
UNT	F	19.83	abcde	12.03	-	607.70	ab	-	-
	Rc	19.66	abcd	12.84	-	652.30	ab	0.81	6.73
D	F	19.33	abc	12.59	-	651.20	ab	0.56	4.66
	Rc	20.16	bcde	12.29	-	612.00	ab	0.26	2.16
C	F	20.66		12.17	-	587.60	ab	0.14	1.16
	Rc	20.16	bcde	11.62	-	573.00	a	-0.41	-3.41
GW1	F	19.83	abcde	13.02		657.00	ab	0.99	8.23
	Rc	19.83	abcde	12.96	-	653.10	ab	0.93	7.73
BC1	F	18.83	a	11.53	-	612.30	ab	-0.50	-4.16
	Rc	19.83	abcde	11.94	-	600.40	ab	-0.09	-0.75
BC2	F	20.00	abcde	12.07	-	604.20	ab	0.04	0.33
	Rc	19.66	abcd	12.68	-	643.60	ab	0.65	5.40
V	F	21.00	e	12.50	-	602.70	ab	0.47	3.91
	Rc	19.50	abcd	12.71	-	652.90	ab	0.68	5.65
HA	F	19.50	abcd	12.32	-	631.70	ab	0.29	2.41
	Rc	20.66	de	12.69	-	612.30	ab	0.66	5.49
SS	F	19.50	abcd	12.52		641.80	ab	0.49	4.07
	Rc	19.66	abcd	12.07	-	616.40	ab	0.04	0.33
GW2	F	19.50	abcd	12.29	-	629.10	ab	0.26	2.16
	Rc	20.33	cde	12.65	-	620.80	ab	0.62	5.15
GW3	F	20.00	abcde	13.33	-	667.30	b	1.30	10.81
	Rc	19.50	abcd	12.75	-	654.00	ab	0.72	5.99
MO	F	20.00	abcde	12.28	-	613.40	ab	0.25	2.08
	Rc	19.50	abcd	12.28	-	629.80	ab	0.25	2.08
MM	v	20.33	cde	13.06	-	643.40	ab	1.03	8.56
	V	19.00	ab	12.28	-	645.20	ab	0.25	2.08
PO	F	19.33	abc	12.58	-	649.30	ab	0.55	4.57
	Rc	20.16	bcde	12.25	-	610.50	ab	0.22	1.83
N	F	20.33	cde	12.74	-	627.20	ab	0.71	5.90
	Rc	19.66	abcd	12.43	-	633.10	ab	0.40	3.33
LSD		**6.41**		**1.84**		**87.51**			
P<0.05		**sig**		**Nsig**		**sig**			

Appendix 6.52. Long Term Trial No. 2: Parsnip yield (rotation 4).

PSY4 HARVEST 26/03/2010									
Soil treatments amendments		(Y) Plant production (#plants/plot)		(W)Yield Kg/Plot		(W/Y) parsnip Weight average g/Plant		Increase yield production (Treat-Unt)	
								∆W=W-Wo	%∆W (W-Wo)/Wo
UNT	F	38.75	a	5.18	ab	135	abc	-	-
	Rc	38.75	a	5.25	b	132	abc	-	-
D	F	34.33	a	5.11	ab	150	c	-0.06	-8.55
	Rc	39.50	a	5.13	ab	127	ab	-0.045	1.93
C	F	39.00	a	4.96	ab	126	a	-0.21	0.48
	Rc	39.25	a	4.59	a	122	a	-0.58	1.29
GW1	F	-	-	-		-	-	-	-
	Rc	-	-	-		-	-	-	-
BC1	F	36.50	a	5.075	ab	140	abc	-0.15	-5.80
	Rc	37.50	a	5.23	b	142	abc	0.05	-3.22
BC2	F	35.00	a	4.97	ab	143	abc	-0.20	-7.25
	Rc	38.00	a	5.35	b	137	abc	0.17	-1.93
V	F	36.00	a	5.26	b	145	bc	0.08	-7.09
	Rc	40.25	a	5.39	b	132	abc	0.21	3.87
HA	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
SS	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
GW2	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
GW3	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
MO	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
MM	v	38.25	a	5.17	ab	135	abc	-0.01	-1.29
	V	36.25	a	5.00	ab	135	abc	-0.17	-6.45
PO	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
N	F	-	-	-	-	-	-	-	-
	Rc	-	-	-	-	-	-	-	-
LSD P<0.05		6.41		0.60		20.46			
		N sig		sig		sig			

Appendix 6.53. Long Term Trial No. 2: Crop disease assessment rotation 1 (lettuce).

PS1DS (lettuce) Harvest 02/09/2008			
Soil Treatment amendments		% Disease incidence (DI)	
UNT	F	11.67	ab
	Rc	13.73	ab
D	F	17.07	b
	Rc	5.88	a
C	F	10.28	ab
	Rc	7.70	a
GW1	F	11.88	ab
	Rc	11.03	ab
BC1	F	-	-
	Rc	-	-
BC2	F	-	-
	Rc	-	-
V	F	16.97	b
	Rc	9.62	ab
HA	F	10.56	ab
	Rc	7.98	a
SS	F	8.05	a
	Rc	10.28	ab
GW2	F	13.48	ab
	Rc	11.24	ab
GW3	F	13.65	ab
	Rc	9.75	ab
MO	F	12.15	ab
	Rc	8.56	ab
MM	v	13,34	ab
	V	10.31	ab
PO	F	13.70	ab
	Rc	13.28	ab
N	F	8.72	ab
	Rc	13.54	ab
LSD		**9.62**	
F ratio		**0.81**	
P<0.05		**0.71**	

PS1DS (lettuce) Harvest 02/09/2008		
Soil Treatment amendments	% Disease incidence (DI)	
UNT	12.70	a
D	11.47	a
C	9.49	a
GW1	11.45	a
BC1	-	-
BC2	-	-
V	13.29	a
HA	8.84	a
SS	9.17	a
GW2	12.32	a
GW3	11.70	a
MO	10.35	a
MM	11.82	a
PO	13.49	a
N	11.13	a
LSD	**6.10**	
F ratio	**0.48**	
P<0.05	**0.91**	

PS1DS (lettuce) Harvest 02/09/2008		
pretr	% Disease incidence (DI)	
F	12.41	a
V	10.24	a
LSD	**2.25**	
F ratio	**3.67**	
P<0.05	**0.05**	

Appendix 6.54. Long Term Trial No. 2: Crop disease assessment rotation 4 (parsnip).

PS4Y (parsnip) Harvest 26/03/2010			
Soil Treatment amendments		% Disease incidence (DI)	
UNT	F	15.71	abc
	Rc	42.03	d
D	F	23.20	bcd
	Rc	24.21	cd
C	F	0.00	a
	Rc	25.94	cd
GW1	F	-	-
	Rc	-	-
BC1	F	3.02	ab
	Rc	14.33	abc
BC2	F	10.05	abc
	Rc	4.37	ab
V	F	4.39	ab
	Rc	13.20	abc
HA	F	-	-
	Rc	-	-
SS	F	-	-
	Rc	-	-
GW2	F	-	-
	Rc	-	-
GW3	F	-	-
	Rc	-	-
MO	F	-	-
	Rc	-	-
MM	v	2.00	a
	V	15.23	abc
PO	F	-	-
	Rc	-	-
N	F	-	-
	Rc	-	-
LSD		18.71	
F ratio		3.07	
P<0.05		0.0034	

PS4Y (parsnip) Harvest 26/03/2010		
Soil Treatment amendments	% Disease incidence (DI)	
UNT	28.87	c
D	23.78	bc
C	14.82	abc
GW1	-	-
BC1	8.67	ab
BC2	6.81	a
V	8.79	ab
HA	-	-
SS	-	-
GW2	-	-
GW3	-	-
MO	-	-
MM	8.61	ab
PO	-	-
N	-	-
LSD	15.38	
F ratio	2.65	
P<0.05	0.02	

PS4Y (parnley) Harvest 26/03/2010		
pretr	% Disease incidence (DI)	
F	8.01	a
V	19.9	b
LSD	8.34	
F ratio	8.18	
P<0.05	0.006	

Appendix 6.55. Long Term Trial No. 2: Pre-treatment soil chemistry.

PS1-PP	**Split plot treatments**	
Indicator	**Mean**	**$SME_{(a)}$**
pH & EC		
pH $CaCl_2$	6.62	0.33
pH H_2O	6.85	0.28
EC (dS/m)	0.52	0.14
TSS	0.18	0.05
Amonium acetate cations with prewash		
Ca (meq/100g)	4.53	0.58
Mg (meq/100g)	1.18	0.24
K(meq/100g)	0.52	0.11
Na (meq/100g)	0.09	0.02
Ca/Mg	3.85	0.34
%Ca	71.83	1.83
%Mg	18.83	1.17
%K	8.17	0.75
%Na	1.17	0.41
Σf4 (meq/100g)	6.33	0.95
Total C/N (g/100g)		
Tot N	0.11	0.01
Tot C	1.38	0.12
Organic matter	2.58	0.18
Available N-P-K-S (meq/Kg)		
NH_4	0.00	0.00
NO_3^-	69.00	8.39
K	456.67	81.16
P (Oslen)	92.33	14.32
S	114.83	49.81
DTA extractable trace elements mg/Kg		
Cu	1.17	0.21
Fe	47.33	4.72
Mn	2.50	0.55
Zn	5.97	0.29
Oxidable organic carbon (ppm)		
Organic carbon	1.52	0.17
Organic matter	2.8	0.36
Lab C	667.68	68.98

[a]SME is square mean error from ANOVA

Appendix 6.56. Long Term Trial No. 2: Pre-plant soil chemistry, rotation 1 (lettuce).

PS1-P **Planting 07/07/08**

Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	Unt	D	C	Gw1	Gw2	BC 1	BC2	MO	
pH CaCl	6.56	6.50	6.6	6.73	6.70	-	-	6.80	6.40	6.43	6.6	6.40	6.53	-	-	6.7	**0.65 N sig**
pH H2O	6.86	7.00	7.16	7.30	7.13	-	-	7.33	7.2	6.90	7.06	6.86	7.26	-	-	7.40	**0.58 N sig**
EC(dS/m)	0.33	0.27	0.22	0.24	0.23	-	-	0.25	0.27	0.26	0.27	0.23	0.19	-	-	0.23	**0.13 N sig**
TSS	0.11	0.09	0.07	0.08	0.07	-	-	0.08	0.09	0.09	0.09	0.08	0.06	-	-	0.08	**0.04 N sig**
Ca (meq/100g)	4.63	4.43	4.26	4.26	4.00	-	-	4.76	4.53	4.33	4.46	4.26	4.20	-	-	4.30	**0.98 N sig**
Mg (meq/100g)	1.36	1.10	1.16	1.20	1.03	-	-	1.26	1.26	1.20	1.14	1.06	1.1	-	-	1.08	**0.407N sig**
Na(meq/100g)	0.12	0.09	0.11	0.11	0.09	-	-	0.12	0.11	0.09	0.10	0.09	0.10	-	-	0.10	**0.04 N sig**
K (meq/100g)	0.62	0.49	0.46	0.49	0.40	-	-	0.53	0.57	0.44	0.48	0.45	0.45	-	-	0.445	**0.20 N sig**
Σf4 (meq/100g)	6.76	6.23	5.96	6.10	5.50	-	-	6.66	6.50	5.93	6.16	5.83	5.86	-	-	6.00	**1.61 N sig**
Ca/Mg	3.33	3.80	3.80	3.53	4.13	-	-	3.76	3.56	4.00	4.06	4.06	3.86	-	-	4.00	**0.70 sig**
%Ca	68.66	71.33	71.33	72.66	73.33	-	-	71.33	70.00	73.33	72.76	70.00	71.66	-	-	72.66	**3.90 sig**
%Mg	20.66	19.00	19.00	20.00	18.00	-	-	19.00	19.66	18.00	18.00	18.00	18.66	-	-	18.66	**2.29 sig**
%K	9.33	8.00	7.66	8.00	7.00	-	-	8.00	8.66	7.66	7.66	8.00	7.33	-	-	7.33	**1.70sig**
%Na	2.00	1.66	2.00	2.00	1.66	-	-	2.00	1.66	1.33	1.66	1.66	2.00	-	-	1.66	**0.74 N sig**
Tot N	0.14	0.11	0.09	0.11	0.08	-	-	0.10	0.14	0.11	0.11	0.11	0.09	-	-	0.01	**0.03 sig**
Tot C	1.70	1.43	1.26	1.43	1.16	-	-	1.36	1.70	1.40	1.20	1.46	1.30	-	-	1.33	**0.36Nsig**
P (Oslen)	95.66	96.00	90.33	94.00	88.66	-	-	96.33	103.00	101.00	103.33	94.33	92.00	-	-	90.00	**23.83 Nsig**
K	470.00	376.66	346.66	386.66	313.33	-	-	390.66	436.66	353.33	380.00	340.00	333.33	-	-	346.66	**150.77N sig**
NH_4	2.26	1.46	1.43	0.80	0.60	-	-	0.80	2.16	1.63	1.06	1.03	8.86	-	-	0.60	**0.76 sig**
NO_3	50.33	36.00	19.66	31.33	18.90	-	-	28.66	51..33	39.00	29.66	21.50	20.46	-	-	17.00	**17.47 sig**
S	35.66	53.00	32.66	39.66	46.00	-	-	46.33	33.66	47.33	55.00	50.00	23.00	-	-	42.00	**43.26 N sig**
Cu	1.36	1.23	1.16	1.20	1.06	-	-	1.20	1.40	1.33	1.33	1.16	1.16	-	-	1.06	**035 N sig**
Fe	71.33	59.33	60.00	65.33	56.33	-	-	68.66	65.00	55.00	61.33	57.00	58.33	-	-	55.66	**17.73 N sig**
Mn	2.66	2.66	2.66	2.33	2.00	-	-	2.00	2.66	2.66	2.00	2.33	2.33	-	-	2.00	**1.15 N sig**
Zn	7.00	5.73	5.60	5.43	4.83	-	-	5.56	7.00	6.13	6.06	6.00	5.83	-	-	5.26	**1.18 sig**

Appendix 6.57. Long Term Trial No. 2: Soil chemistry at harvest, rotation 1 (lettuce).

PS1-H	Harvest 1				Treatments												
	Fallow								Rye corn								**LSD P<0.05**
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
pH CaCl	6.53	6.56	6.66	6.46	6.60	-	-	6.60	6.63	6.40	6.50	6.56	6.46	-	-	6.66	**0.66 N Sig**
pH H_2O	7.10	7.16	7.30	7.13	7.16	-	-	7.26	7.16	6.96	7.06	7.19	7.06	-	-	7.23	**0.63 N Sig**
EC(dS/m)	0.14	0.13	0.15	0.12	0.14	-	-	0.15	0.16	0.16	0.14	0.13	0.12	-	-	0.15	**0.08 N Sig**
TSS	0.05	0.04	0.05	0.04	0.04	-	-	0.05	0.05	0.05	0.05	0.04	0.04	-	-	0.05	**0.02 N Sig**
Ca (meq/100g)	3.93	4.03	4.33	3.96	3.90	-	-	4.36	4.20	4.20	4.20	3.90	3.83	-	-	4.20	**0.82 N Sig**
Mg (meq/100g)	0.94	0.96	1.16	0.95	0.89	-	-	1.05	0.92	0.91	1.08	0.95	0.89	-	-	0.92	**0.31 N Sig**
Na(meq/100g)	0.07	0.07	0.09	0.07	0.07	-	-	0.09	0.08	0.07	0.08	0.08	0.07	-	-	0.07	**0.03 N Sig**
K (meq/100g)	0.35	0.35	0.47	0.35	0.33	-	-	0.43	0.39	0.37	0.42	0.36	0.33	-	-	0.36	**0.20 NSig**
Σf4 (meq/100g)	5.30	5.40	6.07	5.33	5.13	-	-	5.90	5.60	5.73	5.57	5.37	5.17	-	-	5.57	**1.35 Sig**
Ca/Mg	4.30	4.23	3.70	4.26	4.46	-	-	4.13	4.53	4.56	3.96	4.13	4.46	-	-	4.46	**0.85 N Sig**
%Ca	74.67	74.33	71.33	74.67	75.33	-	-	73.33	75.00	75.67	73.33	73.67	75.00	-	-	75.33	**4.94 N Sig**
%Mg	17.33	18.00	19.33	17.67	17.00	-	-	17.67	17.00	16.67	18.33	17.67	17.00	-	-	17.00	**2.13 N Sig**
%K	6.67	6.33	7.67	6.67	6.33	-	-	7.00	7.00	6.67	7.33	7.00	6.33	-	-	6.33	**06.66 N Sig**
%Na	1.30	1.33	1.66	1.30	1.30	-	-	1.66	1.30	0.96	1.30	1.63	1.63	-	-	1.30	**0.97 N Sig**
Tot N	0.10	0.10	0.13	0.11	0.09	-	-	0.11	0.11	0.11	0.13	0.11	0.10	-	-	0.11	**0.03 N Sig**
Tot C	1.23	1.30	1.66	1.40	1.20	-	-	1.36	1.33	1.40	1.56	1.36	1.30	-	-	1.33	**0.31 Sig**
Ratio C/N	12,30	13,00	12,77	12,73	13,33	-	-	12,36	12,09	12,73	12,00	12,36	13,00	-	-	12,09	**0.97 Sig**
% Org. matter	2.26	2.43	3.03	2.60	2.23	-	-	2.50	2.46	2.53	2.93	2.56	2.43	-	-	2.43	**0.57 Sig**
P (Oslen)	92.70	88.00	94.00	96.70	165.70	-	-	94.30	102.7	104.7	102.7	93.70	88.00	-	-	98.70	**71.51 N Sig**
K	257.0	253.00	337.0	260.0	260.0	-	-	303.0	297.0	253.	310.0	263.0	240.0	-	-	283.0	**146.40 N Sig**
NH_4	0.50	0.50	0.83	0.50	0.66	-	-	0.50	0.70	0.70	1.36	0.66	0.50	-	-	0.66	**0.40 Sig**
NO_3	9.70	11.33	11.27	8.83		-	-	11.87	11.33	17.00	14.33	11.87	11.07	-	-	13.10	**5.69 Sig**
S	14.80	17.30	20.30	11.00	17.40	-	-	23.00	25.70	21.30	14.40	17.70	19.80	-	-	21.30	**27.48 N Sig**
Cu	1.10	1.06	1.20	1.20	1.03	-	-	1.06	1.20	1.23	1.40	1.10	1.06	-	-	1.13	**0.32 Sig**
Fe	53.00	59.30	64.7	53.30	52.70	-	-	61.3	54.30	60.70	63.30	57.00	51.30	-	-	54.30	**14.05 N Sig**
Mn	2.33	2.67	3.67	3.33	2.00	-	-	2.33	3.33	3.00	3.00	2.67	2.00	-	-	2.67	**1.73 N Sig**
Zn	5.40	5.23	5.90	5.87	4.77	--	-	5.00	5.53	6.30	6.60	5.37	5.17	-	-	5.43	**0.13 Sig**

Appendix 6.58. Long Term Trial No. 2: Pre-plant soil chemistry, rotation 2 (endive).

PS2-P	**Planting 22/12/2008**																
Chemical properties	**treatments**																**LSD** P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
pH CaCl	6.63	6.46	6.76	6.66	6.63	6.60	6.76	6.70	6.63	6.36	6.53	6.33	6.50	6.56	6.80	6.66	**0.68 N Sig**
pH H2O	7.26	70.6	7.46	7.33	7.26	7.30	7.40	7.36	7.23	6.96	7.20	7.00	7.10	7.26	7.46	7.30	**0.62 N Sig**
EC(dS/m)	0.16	0.21	0.20	0.21	0.17	0.15	0.18	0.17	0.18	0.17	0.16	0.14	0.15	0.17	0.18	0.16	**0.12 N Sig**
TSS	0.05	0.07	0.07	0.07	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.04	0.05	0.06	0.05	0.05	**0.04 N Sig**
Ca (meq/100g)	4.03	3.80	4.30	3.96	3.66	4.26	4.16	4.43	4.06	4.16	4.20	3.83	4.00	4.16	4.00	4.13	**1.12 N Sig**
Mg (meq/100g)	1.05	0.99	1.23	1.07	0.90	1.15	1.15	1.13	1.02	0.98	1.12	0.92	0.98	1.02	1.06	1.02	**0.43 N Sig**
Na(meq/100g)	0.08	0.07	0.10	0.09	0.07	0.09	0.10	0.10	0.08	0.07	0.09	0.07	0.07	0.08	0.07	0.07	**0.05 N Sig**
K (meq/100g)	0.43	0.40	0.52	0.47	0.36	0.48	0.50	0.48	0.43	0.42	0.48	0.40	0.40	0.40	0.42	0.40	**0.27 N Sig**
Sig Σf4 (meq/100g)	5.57	5.27	6.17	5.63	5.00	6.00	5.87	6.13	5.60	5.63	5.93	5.27	5.47	5.70	5.60	5.60	**1.82 N Sig**
Ca/Mg	3.90	3.90	3.46	3.76	4.26	3.83	3.83	3.86	4.10	4.26	3.86	4.10	4.06	4.13	3.83	4.06	**0.79 Sig**
%Ca	72.67	72.33	69.67	71.00	73.67	72.00	71.33	72.00	73.33	74.00	72.00	73.00	73.33	74.00	72.00	72.00	**5.46 N Sig**
%Mg	18.67	18.67	20.33	19.33	17.67	19.00	19.00	18.67	18.00	17.33	18.67	18.00	18.00	17.67	18.67	18.33	**2.22 N Sig**
%K	7.33	7.67	8.33	8.33	7.00	7.33	8.00	8.00	7.67	7.33	8.33	7.67	7.33	6.67	7.67	7.00	**2.88 N Sig**
%Na	1.33	1.33	1.66	1.66	1.33	1.33	1.66	1.66	1.33	1.33	1.66	1.33	1.33	1.33	1.66	1.33	**0.93 N Sig**
Tot N	0.11	0.11	0.13	0.12	0.10	0.10	0.10	0.12	0.12	0.12	0.13	0.12	0.11	0.11	0.11	0.11	**0.03 N Sig**
Tot C	1.36	1.36	1.53	1.43	1.23	1.36	1.26	1.46	1.43	1.43	1.53	1.46	1.36	1.36	1.33	1.36	**0.33 N Sig**
C/N	11.77	11.64	11.75	11.35	11.80	13.05	11.83	11.51	11.35	11.95	11.51	12.22	11.81	12.42	12.10	11.72	**1.58 Sig**
P (Oslen)	95.00	98.30	104.30	107.00	97.70	94.00	100.00	99.00	107.70	105.00	108.00	90.70	97.00	104.30	115.70	109.30	**37.30 N Sig**
K	327	307	367	370	287	290	350	330	333	317	333	297	297	297	330	310	**166 N Sig**
NH_4	0.89	1.13	0.86	1.06	0.96	0.79	0.86	0.73	0.96	1.10	1.10	1.03	0.83	0.86	0.90	0.89	**0.28 Sig**
NO_3	27.30	34.00	31.70	34.3	32.30	25.00	31.30	28.30	30.70	29.70	26.70	27.00	26.30	31.70	27.70	25.70	**18.83 N Sig**
S	14.70	38.30	25.00	27.30	20.30	13.00	21.00	20.30	23.70	26.30	14.00	11.70	12.00	22.30	12.70	16.30	**27.48 N Sig**
Cu	1.36	1.40	1.46	1.53	1.23	1.26	1.26	1.33	1.43	1.36	1.50	1.40	1.36	1.33	1.50	1.36	**0.38 N Sig**
Fe	53.70	59.70	63.70	60.00	53.70	57.30	55.70	62.70	56.30	57.70	61.70	58.30	53.70	58.70	53.30	54.70	**15.82 N Sig**
Mn	2.00	2.33	2.33	2.67	2.33	3.00	2.00	2.00	2.33	2.00	2.33	2.00	2.00	2.00	2.33	2.67	**1.22 N Sig**
Zn	4.96	5.13	5.43	4.43	4.63	5.76	4.73	4.76	5.43	5.66	5.76	5.56	5.43	4.93	5.56	5.23	**1.04 Sig**

Appendix 6.59. Long Term Trial No. 2: Soil chemistry at harvest, rotation 2 (endive).

PS2-H	**Harvest**																
Chemical properties	**treatments**																**LSD** P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
pH CaCl	6.70	6.46	6.73	6.70	6.63	6.60	6.76	6.66	6.66	6.33	6.56	6.36	6.50	6.56	6.83	6.73	**0.64 N Sig**
pH H2O	7.10	6.83	7.16	7.10	7.03	6.93	7.13	7.06	7.10	6.70	6.83	6.70	6.83	6.93	7.23	7.06	**0.64 N Sig**
EC(dS/m)	0.29	0.35	0.36	0.33	0.30	0.34	0.37	0.39	0.34	0.37	0.37	0.33	0.33	0.35	0.33	0.33	**0.13 N Sig**
TSS	0.10	0.12	0.12	0.11	0.10	012	0.12	0.13	0.12	0.13	0.12	0.11	0.11	0.12	0.11	0.11	**0.04 N Sig**
Ca (meq/100g)	4.23	4.10	4.73	4.43	4.23	3.96	4.23	4.76	4.60	4.20	4.36	4.26	4.53	4.40	4.43	4.30	**0.83 N Sig**
Mg (meq/100g)	1.23	1.16	1.46	1.33	1.14	1.17	1.24	1.40	1.29	1.11	1.26	1.16	1.20	1.16	1.30	1.18	**0.38 N Sig**
Na(meq/100g)	0.11	0.10	0.13	0.12	0.10	0.10	0.10	0.12	0.12	0.09	0.11	0.10	0.11	0.10	0.10	0.10	**0.03 N Sig**
K (meq/100g)	0.40	0.44	0.55	0.50	0.40	0.37	0.48	0.50	0.47	0.42	0.40	0.42	0.43	0.39	0.38	0.40	**0.26 N Sig**
Σf4 (meq/100g)	6.00	5.83	6.90	6.40	5.90	5.63	6.07	6.83	6.50	5.80	6.27	6.00	6.30	6.07	6.23	6.00	**1.45 N Sig**
Ca/Mg	3.43	3.53	3.23	3.33	3.73	3.50	3.50	3.46	3.60	3.80	3.46	3.66	3.76	3.76	3.43	3.63	**0.56 Sig**
%Ca	72.67	72.33	69.67	71.00	73.67	72.00	71.33	72.00	73.33	74.00	72.00	73.00	73.33	74.00	72.00	73.33	**5.46 N Sig**
%Mg	18.67	18.67	20.33	19.33	17.67	19.00	19.00	18.67	18.00	17.33	18.67	18.00	18.00	17.67	18.67	18.33	**2.22 N Sig**
%K	7.33	7.67	8.33	8.33	7.00	7.33	8.00	8.00	7.67	7.33	8.33	7.67	7.33	6.67	7.67	7.00	**2.95 Sig**
%Na	1.33	1.33	2.00	1.66	1.33	1.33	1.33	1.66	1.33	1.33	1.66	1.33	1.33	1.33	1.66	1.33	**0.93 N Sig**
Tot N	0.09	0.10	0.11	0.10	0.08	0.08	0.09	0.11	0.10	0.11	0.12	0.12	0.10	0.09	0.09	0.10	**0.03 N Sig**
Tot C	1.36	1.36	1.50	1.43	1.18	1.43	1.26	1.53	1.40	1.43	1.53	1.60	1.43	1.40	1.36	1.33	**0.25 Sig**
Ratio C/N	11.77	11.64	11.75	11.35	11.80	13.05	11.83	11.51	11.35	11.95	11.51	12.22	11.81	12.42	12.10	11.72	**1.58 Sig**
P (Oslen)	95.00	98.30	104.30	107.00	97.70	94.00	100.00	99.00	107.70	105.00	108.00	90.70	97.00	94.00	115.70	109.30	**37.30 N Sig**
K	327	307	367	370	287	290	350	330	333	317	333	297	297	297	330	310	**166.5 N Sig**
NH_4	0.72	0.72	0.72	0.79	0.69	0.69	0.76	0.79	0.69	0.76	0.72	0.69	0.72	0.69	0.79	0.79	**0.14 N Sig**
NO_3	33.3	42.3	43.0	41.3	35.3	34.3	46.0	43.0	37.7	47.0	48.0	42.0	42.7	41.3	33.7	39.0	**17.79 N Sig**
S	14.70	38.30	25.00	27.30	20.30	13.00	21.00	20.30	23.70	26.30	14.00	11.70	12.00	22.30	12.70	16.30	**27.48 Sig**
Cu	1.36	1.43	1.50	1.70	1.33	1.36	1.33	1.40	1.53	1.60	1.60	1.53	1.40	1.16	1.53	1.36	**0.33 Sig**
Fe	44.33	48.67	52.33	50.67	43.67	45.00	40.67	49.67	45.67	45.67	48.00	46.67	44.67	49.00	45.00	43.67	**8.88 Sig**
Mn	2.00	2.33	2.00	3.00	2.33	3.00	2.00	2.00	2.66	3.00	2.33	2.66	2.33	2.66	2.33	2.00	**0.67 N Sig**
Zn	5.30	5.33	5.60	5.80	4.90	5.10	5.06	5.00	5.73	6.23	6.43	6.16	5.83	5.33	5.73	5.46	**1.10 Sig**

Appendix 6.60. Long Term Trial No. 2: Soil chemistry at harvest, rotation 3 (leek).

PS3H	Harvest																
Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	
pH CaCl	6.70	6.70	6.83	6.80	6.73	6.76	6.90	6.80	6.73	6.66	6.70	6.53	6.63	6.73	6.63	6.83	**0.68 N Sig**
pH H_2O	7.13	7.20	7.26	7.33	7.16	7.20	7.33	7.26	7.23	7.10	7.16	7.03	7.10	7.20	7.40	7.30	**0.62 N Sig**
EC(dS/m)	0.17	0.23	0.35	0.23	0.21	0.25	0.36	0.24	0.22	0.27	0.24	0.16	0.17	0.20	0.18	0.20	**0.20 N Sig**
TSS	0.05	0.08	0.11	0.08	0.07	0.08	0.12	0.08	0.07	0.09	0.08	0.05	0.06	0.07	0.06	0.07	**0.07 N Sig**
Ca (meq/100g)	4.20	4.36	4.66	4.50	4.43	4.23	4.30	4.76	4.43	4.56	4.66	4.16	4.20	4.33	4.33	4.50	**0.88 N Sig**
Mg (meq/100g)	1.20	1.23	1.46	1.22	1.28	1.36	1.17	1.36	1.24	1.23	1.25	1.13	1.17	1.23	1.23	1.24	**0.43 N Sig**
Na(meq/100g)	0.10	0.12	0.16	0.15	0.11	0.12	0.12	0.15	0.12	0.13	0.14	0.12	0.12	0.13	0.12	0.13	**0.08 N Sig**
K (meq/100g)	0.32	0.38	0.48	0.44	0.31	0.33	0.41	0.42	0.37	0.38	0.38	0.33	0.34	0.35	0.29	0.34	**0.21 N Sig**
Σf4 (meq/100g)	5.87	6.70	6.13	6.47	5.73	5.93	6.20	6.70	6.17	6.27	6.23	5.77	5.80	6.07	5.97	6.23	**1.56 N Sig**
Ca/Mg	3.60	3.56	3.23	3.43	3.70	3.53	3.36	3.50	3.63	3.73	3.50	3.70	3.76	3.56	3.53	3.63	**0.66 N Sig**
%Ca	72.67	71.33	69.00	70.33	73.00	70.33	73.00	71.00	72.33	72.33	71.33	72.33	72.67	72.33	72.67	72.33	**5.16 N Sig**
%Mg	20.33	20.33	21.33	20.67	20.00	20.67	21.33	20.33	19.67	19.33	20.33	19.67	19.67	20.33	20.67	20.00	**2.47 N Sig**
%K	5.67	6.33	7.00	6.67	5.33	5.33	6.33	6.33	5.67	6.00	6.00	5.67	5.67	5.67	4.67	5.67	**2.29 N Sig**
%Na	2.00	2.33	2.33	2.33	2.00	2.33	1.66	2.33	1.66	2.00	2.33	2.33	2.33	2.00	2.33	2.33	**0.92 N Sig**
Tot N	0.08	0.09	0.10	0.09	0.08	0.08	0.08	0.10	0.39	0.10	0.10	0.10	0.09	0.08	0.09	0.09	**0.21 Sig**
Tot C	1.30	1.36	1.46	1.36	1.19	1.26	1.30	1.46	1.40	1.40	1.46	1.40	1.36	1.30	1.33	1.36	**0.28 Sig**
Organic matter	3.00	3.00	3.13	3.13	2.63	2.73	2.96	3.13	2.96	3.13	3.16	3.06	3.03	2.83	3.00	2.96	**0.68 N Sig**
P (Oslen)	80.00	84.00	93.00	93.00	86.00	80.70	85.00	81.30	91.30	88.00	88.70	75.00	81.70	82.00	88.70	88.70	**34.84 N Sig**
K	197	240	320	267	212	214	293	267	237	247	250	207	223	220	191	223	**160.8 N Sig**
NH_4^+	0.05	0.05	0.36	0.26	0.33	0.05	0.30	0.26	0.05	0.26	0.55	0.05	0.30	0.40	0.26	0.36	**0.63 N Sig**
NO_3^-	5.87	6.27	19.23	6.10	6.90	3.97	14.23	9.43	6.13	6.77	7.43	5.73	6.93	5.03	5.27	5.10	**9.93 N Sig**
S	25.70	44.00	70.00	39.70	37.30	47.30	70.00	49.30	40.00	65.00	54.30	27.30	26.70	40.70	30.00	33.00	**55.85 N Sig**
Cu	2.20	2.06	2.40	2.60	2.06	2.00	2.20	2.26	2.26	2.30	2.30	2.16	2.00	2.16	2.40	2.13	**0.69 N Sig**
Fe	52.33	55.00	59.00	57.33	49.00	50.00	48.33	58.67	53.00	53.00	57.33	55.00	54.00	55.67	54.67	51.67	**9.65 Sig**
Mn	2.33	2.66	2.66	3.00	2.66	2.33	2.33	2.66	2.66	2.33	2.66	2.33	2.33	2.66	2.66	2.66	**0.92 N Sig**
Zn	5.33	5.30	5.83	5.83	5.06	5.00	5.26	5.46	5.63	5.96	6.06	5.66	5.70	5.66	5.70	5.50	**0.86 Sig**

Appendix 6.61. Long Term Trial No. 2: Pre-plant soil carbon, rotation 1 (lettuce).

PS1-P	Planting 07/07/08																
Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
Organic carbon	1.66	1.43	1.33	1.33	1.2	-	-	1.33	1.70	1.43	1.43	1.43	1.36	-	-	1.30	**0.27 Sig**
Organic matter	3.10	2.66	2.50	2.53	2.23	-	-	2.45	3.13	2.66	2.63	2.66	2.50	-	-	2.36	**0.54 Sig**

Appendix 6.62. Long Term Trial No. 2: Soil carbon at harvest, rotation 1 (lettuce).

PS1-H	Harvest 02/09/2008																
Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
Organic carbon	1.26	1.33	1.63	1.43	1.23	-	-	1.46	1.36	1.43	1.56	1.43	1.30	-	-	1.36	**0.47 Sig**
Organic matter	2.33	2.40	3.03	2.70	2.30	-	-	2.73	2.60	2.66	2.83	2.63	2.50	-	-	2.56	**0.61 Sig**
Lab Carbon	502.7	515.87	585.45	560.1	509.58	-	-		574.21	589.54	585.38	539.50	479.76	-	-	-	**0.82 N Sig**
CO_2 reps. (4 days)	228.7	228.61	328.94	291.8	236.07	-	-		273.3	265.7	288.10	221.52	243.79	-	-	-	**0.47 Sig**
CO_2 reps. (14 days)	512.8	475.24	698.94	606.6	494.17	-	-		572.3	579.4	623.7	479.44	536.88	-	-	-	**0.14 Sig**

Appendix 6.63. Long Term Trial No. 2: Pre-plant soil carbon, rotation 2 (endive).

PS2-P	Planting 09/12/2008																
Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	
Organic carbon	1.36	1.33	1.53	1.46	1.26	1.33	1.20	1.50	1.43	1.43	1.53	1.50	1.33	1.40	1.30	1.33	**0.30 Sig**
Organic matter	2.53	2.50	2.83	2.76	2.33	2.50	2.26	2.80	2.66	2.70	2.83	276	2.50	2.63	2.43	2.43	**0.55 Sig**
Lab Carbon	463.00	479.00	507.00	517.30	417.30	430.00	454.30		547.70	507.70	571.30	564.00	490.00	457.70	507.00	-	**104.50 Sig**

Appendix 6.64. Long Term Trial No. 2: Soil carbon at harvest, rotation 2 (endive).

PS2-H	Harvest 26/01/2009																
Chemical properties	treatments																LSD F ratio P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	D	C	Gw1	Gw2	BC1	BC2	V	Unt	D	C	Gw1	Gw2	BC1	BC2	V	
Organic carbon	1.36	1.33	1.53	1.46	1.26	1.33	1.20		1.43	1.43	1.53	1.50	1.33	1.40	1.30		**0.30 N Sig**
Organic matter	2.80	2.50	2.83	22.76	2.33	2.50	2.26		2.53	2.70	2.83	2.76	2.50	2.63	2.43		**0.55 Sig**
Lab Carbon	463.0	479.0	507.0	517.3	417.3	430.0	454.3	545.0	547.7	507.7	571.3	564.0	490.7	457.7	507.3	482.7	**104.50 Sig**
CO_2 reps. (4 days)	295.2	272.9	332.3	261.8	269.2	261.8	269.2	287.8	310.0	291.5	302.6	317.4	276.6	284.0	310.0	310.0	**73.57 N Sig**
CO_2 reps. (14 days)	677.	640.	748.	544.	588.	603.	599.	666.	696.	629.	710.	696.	618.	659.	677.	647.	**152.10 Sig**

Appendix 6.65. Long Term Trial No. 2: Soil carbon at harvest, rotation 3 (leek).

PS3-H	**Harvest 24/08/2009**																
Chemical properties	**treatments**																**LSD** F ratio P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
Organic carbon	1.63	1.63	1.66	1.66	1.40	1.46	1.63	1.70	1.60	1.66	1.73	1.63	1.40	1.53	1.63	1.63	**0.35 N Sig**
Organic matter	3.00	3.00	3.13	3.13	2.63	2.83	3.00	3.13	2.96	3.13	3.16	3.06	3.03	2.83	3.00	2.96	**0.68 N Sig**

Appendix 6.66. Long Term Trial No. 2: Pre-plant nematode parameters, rotation 1 (lettuce).

PS1P-bio	**Planting 30/06/08**																
Chemical properties	**Treatments**																**LSD** P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
PP	0.00	0.00	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-
FF	8.70	2.60	9.90	14.10	6.10	-	-	5.30	16.70	13.40	20.10	44.60	19.30	-	-	11.60	**14.81 Sig**
BF	217	59	176	253	270	-	-	135	237	378	357	425	239	-	-	248	**279.9 Sig**
P	2.23	0.47	1.51	2.84	2.84	-	-	1.96	0.00	5.67	0.00	2.87	4.54	-	-	1.81	**7.00 Sig**
O	38.30	7.40	20.90	63.30	36.40	-	-	15.30	45.90	19.40	55.90	77.60	56.30	-	-	26.40	**77.42 Sig**
TFN	267	69	208	333	315	-	-	158	299	417	432	550	319	-	-	288	**331.00 Sig**
%FLN	100	100	100	100	100	-	-	100	100	100	100	100	100	-	-	100	-
EI	98.57	98.80	97.56	98.43	99.24	-	-	98.64	97.84	97.90	95.03	94.91	97.58	-	-	98.64	**3.56 Sig**
SI	94.50	88.00	86.40	87.70	93.30	-	-	90.60	78.50	59.30	59.10	75.50	61.80	-	-	87.30	**37.15 Sig**
H´	0.70	0.55	0.66	0.66	0.54	-	-	0.54	0.55	0.36	0.83	0.96	0.85	-	-	0.54	**0.55 Sig**
CI	0.81	1.02	1.62	1.24	0.56	-	-	1.10	2.21	1.76	1.21	3.22	0.57	-	-	1.18	**1.84 Sig**
B/F	0.96	0.96	0.94	0.95	0.97	-	-	0.95	0.93	0.96	0.94	0.89	0.91	-	-	0.95	**0.06 Sig**
PFL	0.00	0.00	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.00	-

Appendix 6.67. Long Term Trial No. 2: Nematode parameters at harvest, rotation 1 (lettuce).

PS1H-Bio	**Harvest 02/09/08**																
Chemical properties	**Treatments**																**LSD** P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
TFN	1571	665	1220	1500	1260	-	-	2243	1425	1505	2717	1643	1867	-	-	1872	**13.90.7 N Sig**
FF	46.20	20.10	50.50	35.20	100.4	-	-	96.70	41.60	48.90	106.0 0	33.70	97.00	-	-	39.80	**73.79 N Sig**
BF	1399	613	1093	1360	1109	-	-	1931	1337	1305	2508	1550	1619	-	-	1695	**1305 N Sig**
P	1.60	0.00	0.00	0.00	0.00	-	-	0.00	0.00	0.00	18.2	0.00	8.6	-	-	0.00	**17.06 N Sig**
O	124	32	77	105	50	-	-	215	46	151	85	59	143	-	-	137	**146.60 N Sig**
TN	1571	665	1220	1500	1260	-	-	2243	1425	1505	2717	1643	1867	-	-	1872	**1390.7 N Sig**
%FLN	100	100	100	100	100	-	-	100	100	100	100	100	100	-	-	100	-
EI	98.40	98.70	98.14	97.24	96.6	-	-	98.33	98.36	97.99	98.79	98.70	98.25	-	-	98.89	**1.94 N Sig**
SI	88.6	77.5	77.0	70.9	60.5	-	-	84.	72.4	79.4	80.5	79.4	83.4	-	-	88.0	**22.36 N Sig**
CI	1.14	0.99	1.20	1.99	1.97	-	-	1.33	0.94	0.79	0.88	0.33	1.21	-	-	0.82	**1.39 Sig**
B/F	0.96	0.97	0.95	0.97	0.93	-	-	0.94	0.96	0.96	0.95	0.97	0.94	-	-	0.96	**0.04 N Sig**
H’	0.66	0.44	0.63	0.53	0.56	-	-	0.59	0.47	0.56	0.43	0.47	0.61	-	-	0.52	**0.34 N Sig**
PFL	0.00	0.00	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.00	-

Appendix 6.68. Long Term Trial No. 2: Pre-plant nematode parameters, rotation 2 (endive).

PS2P-bio	**Planting 09/12/08**																
Chemical properties	**treatments**																**LSD** P<0.05
	Fallow								**Rye corn**								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	**Unt**	**D**	**C**	**Gw1**	**Gw2**	**BC1**	**BC2**	**MO**	
TFN	428	141	289	515	298	322	380	281	326	217	292	368	239	322	411	400	**359.5Sig**
FF	37.70	10.90	18.60	24.70	19.80	58.30	31.10	7.20	28.70	9.60	28.40	18.40	19.80	58.40	19.50	20.60	**37.28 Sig**
BF	347	127	261	389	241	287	332	231	244	199	257	300	215	229	367	356	**287.6 N Sig**
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
O	43.60	3.00	9.40	101.5	32.20	19.10	15.90	43.10	53.3	8.70	8.40	48.20	17.40	34.00	24.30	23.20	**88.48 N Sig**
TN	428	141	289	515	296	364	380	281	326	217	292	368	239	322	411	400	**359.5 N Sig**
%FLN	100	100	100	100	100	100	100	66.7	100	100	100	100	100	100	100	100	**24.01 N Sig**
EI	95.60	96.10	96.80	97.60	94.00	92.80	97.10	63.70	96.50	97.80	95.30	94.70	97.50	93.60	96.00	97.60	**23.48 N Sig**
SI	63.90	42.70	59.30	71.60	76.80	41.10	59.10	57.20	73.40	65.50	45.90	74.00	75.70	47.50	58.90	75.30	**38.66 N Sig**
CI	2.96	2.23	1.69	1.32	2.07	5.07	1.98	0.75	3.02	1.87	2.99	1.90	2.07	5.46	1.92	1.31	**2.45 Sig**
B/F	0.87	0.92	0.93	0.95	0.93	0.84	0.92	0.64	0.89	0.93	0.90	0.94	0.97	0.82	0.93	0.95	**0.24 N Sig**
H'	0.78	0.60	0.65	0.63	0.88	0.94	0.61	0.60	0.77	0.49	0.66	0.95	0.57	0.95	0.57	0.55	**0.62 N Sig**
PFL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

Appendix 6.69. Long Term Trial No. 2: Nematode parameters at harvest, rotation 4 (parsnip).

PS4H-bio	26/03/2010																
Chemical properties	treatments																LSD P<0.05
	Fallow								Rye corn								
	Control		Carbon amendments					Bf	Control		Carbon amendments					Bf	
	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	Unt	D	C	Gw1	Gw2	BC1	BC2	MO	
PP	0.00	0.00	0.00	-	-	0.00	1.42	-	0.00	0.00	5.62	-	-	4.05	6.37	-	**8.25 N Sig**
FF	10.20	18.60	15.70	-	-	12.90	15.70	-	21.40	5.30	23.50	-	-	27.00	18.70	-	**23.52 N Sig**
BF	553.00	643.00	404.00	-	-	533.00	423.00	-	954.00	322.00	578.00	-	-	423.00	637.00	-	**702.4 N Sig**
TPN	13.90	32.2	5.30	-	-	1.70	22.30	-	42.50	11.60	9.00	-	-	2.00	9.60	-	**33.35 N Sig**
TON	19.10	47.80	28.20	-	-	69.20	33.30	-	43.10	29.40	59.20	-	-	31.00	40.50	-	**56.37N Sig**
TN	597.00	742.00	453.00	-	-	617.00	496.00	-	1061.00	368.00	675.00	-	-	487.00	712.00	-	**743.50 N Sig**
TFLN	597.00	742.00	453.00	-	-	617.00	494.00	-	1061.00	368.00	669.00	-	-	483.00	706.00	-	**746.50 N Sig**
%FLN	100	100	100	-	-	100	99.29	-	100	100	97.92	-	-	98.69	98.67	-	**2.47 N sig**
EI	92.40	95.80	95.70	-	-	93.80	98.20	-	94.40	95.60	90.40	-	-	93.20	93.6	-	**10.02 N Sig**
SI	68.60	73.80	72.80	-	-	62.70	44.00	-	79.20	79.70	65.80	-	-	63.60	72.20	-	**26.72 N Sig**
CI	0.54	0.88	1.06	-	-	1.02	1.31	-	0.72	0.48	1.85	-	-	1.77	1.07	-	**1.41 N sig**
B/F	1.04	0.95	0.88	-	-	0.85	1.07	-	0.94	0.84	1.20	-	-	0.98	1.00	-	**0.87 Sig**
PFL	0.98	0.97	0.96	-	-	0.96	0.96	-	0.97	0.98	0.95	-	-	0.94	0.97	-	**0.03 N sig**

Appendix 6.70. Long Term Trial No. 2: FDA hydrolysis (biological activity) in soil at planting (P) and harvest (H). Interaction between main and split-plot treatments.

FDA		**PS1P (lettuce)**		**PS1H (lettuce)**		**PS2P (endive)**		**PS2H (endive)**		**PS4P (parsnip)**	
UNT	**F**	0.65	bcde	0.90	ab	0.54	ab	0.83	bc	0.47	a
	Rc	0.59	bcde	0.67	ab	0.64	ab	0.75	abc	0.86	a
D	**F**	0.51	bcde	0.91	ab	0.44	ab	0.51	ab	0.69	a
	Rc	0.63	bcde	0.83	ab	0.36	a	0.67	abc	0.60	a
C	**F**	0.74	cdef	1.19	b	0.41	ab	0.87	c	0.65	a
	Rc	0.75	cdef	1.03	ab	0.85	b	0.87	c	0.74	a
GW1	**F**	0.15	a	1.04	ab	0.70	ab	0.86	c	---	
	Rc	0.52	bcde	0.77	ab	0.67	ab	0.73	abc	---	
BC1	**F**	-	-	-	-	0.48	ab	0.50	a	0.60	a
	Rc	-	-	-	-	0.66	ab	0.89	c	0.54	a
BC2	**F**	-	-	-	-	0.56	ab	0.70	abc	0.57	a
	Rc	-	-	-	-	0.65	ab	0.81	bc	0.85	a
V	**F**	0.15	a	1.07	ab	-	-	-	-	0.52	a
	Rc	0.73		0.41	a	-	-	-	-	0.68	a
HA	**F**	0.15	a	1.02	ab	-	-	-	-	-	-
	Rc	1.01	f	0.76	ab	-	-	-	-	-	-
SS	**F**	0.15	a	1.03	ab	-	-	-	-	-	-
	Rc	0.63	bcde	0.64	ab	-	-	-	-	-	-
GW2	**F**	0.38	ab	0.87	ab	0.41	a	0.61	abc	-	-
	Rc	0.62	bcde	0.60	ab	0.29	a	0.82	c	-	-
GW3	**F**	0.43	abc	0.84	ab	-	-	-	-	-	-
	Rc	0.79	def	0.87	ab	-	-	-	-	-	-
MO	**F**	-	-	0.69	ab	0.69	ab	0.80	bc	-	-
	Rc	-	-	0.55	ab	0.50	ab	0.80	bc	-	-
MM	**v**	0.15	a	0.86	ab	-	-	-	-	0.58	a
	V	0.84	ef	0.91	ab	-	-	-	-	0.67	a
PO	**F**	0.50	abcde	0.80	ab	-	-	-	-	-	-
	Rc	0.46	abcd	0.77	ab	-	-	-	-	-	-
N	**F**	0.15	a	0.69	ab	-	-	-	-	-	-
	Rc	0.57		0.68	ab	-	-	-	-	-	-
LSD		0.35		0.70		0.43		0.28		0.39	
F ratio		4.10		0.53		0.98		1.41		0.72	
P<0.05		0.00		0.95		0.50		0.20		0.73	

Appendix 6.71. Long Term Trial No. 2: FDA hydrolysis (biological activity) in soil at planting (P) and harvest (H). Split-plot treatment effects.

FDA	PS1P Planting 02/09/2008		PS1H Harvest		PS2P Planting		PP2H Harvest		PS4P Planting	
UNT	0.62	ab	0.78	ab	0.59	ab	0.79	ab	0.66	a
D	0.57	ab	0.87	ab	0.40	ab	0.62	a	0.64	a
C	0.74	b	1.11	b	0.63	ab	0.87	b	0.70	a
GW1	0.33	a	0.90	ab	0.68	b	0.80	ab	-	-
BC1	-	-	-	-	0.57	ab	0.70	ab	0.57	a
BC2	-	-	-	-	0.61	ab	0.76	ab	0.71	a
V	0.44	ab	0.74	ab	-	-	-	-	0.60	a
HA	0.58	ab	0.89	ab	-	-	-	-	-	-
SS	0.39	ab	0.83	ab	-	-	-	-	-	-
GW2	0.50	ab	0.74	ab	0.35	a	0.72	ab	-	-
GW3	0.61	ab	0.85	ab	-	-	-	-	-	-
MO	-	-	0.62	a	0.59	ab	0.80	ab	-	-
MM	0.49	ab	0.88	ab	-	-	-	-	0.63	a
PO	0.48	ab	0.78	ab	-	-	-	-	-	-
N	0.36	a	0.68	ab	-	-	-		-	-
LSD	**0.35**		**0.47**		**0.30**		**0.20**		**0.28**	
F ratio	**0.90**		**0.53**		**1.23**		**1.11**		**0.27**	
P<0.05	**0.54**		**0.88**		**0.31**		**0.37**		**0.94**	

Appendix 6.72. Long Term Trial No. 2: FDA hydrolysis (biological activity) in soil at planting (P) and harvest (H). Main-plot treatment effects.

FDA	PS1P Planting 02/09/2008		PS1H Harvest		PS2P Planting		PS2H Harvest		PS4P Planting	
F	0.34	a	0.73	a	0.53	a	0.72	a	0.58	a
Rc	0.68	b	0.91	b	0.58	a	0.79	a	0.71	a
LSD	**0.12**		**0.17**		**0.15**		**0.10**		**0.13**	
F ratio	**30.61**		**4.56**		**0.40**		**2.08**		**3.40**	
P<0.05	**0.00**		**0.03**		**0.53**		**0.15**		**0.07**	

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

7.1 Summary

- 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.
- In this experiment, 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 composted and composted chicken manure had the lowest C:N ratio of the organic amendments used, and consequently were the only organic amendment 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 both organic amendments and full nitrogen fertiliser rates.

7.2 Introduction

The Vegetable Industry is heavily reliant on soil cultivation for maintaining suitable soil structure, managing crop residues and controlling weeds and disease. However, this continual cultivation contributes to a decline in soil carbon levels and inherent soil fertility. To combat this decline in soil carbon and soil fertility, vegetable growers are interested in the effectiveness of applying organic amendment to the soil.
A long-term experiment was established on a sandy soil at Boneo, on the Mornington Peninsula in Victoria, to determine if the addition of various organic amendments could increase and maintain soil organic carbon levels and reduce requirements for the addition of inorganic fertilisers.

7.3 Methods

A long-term experiment was established on a sandy soil at Boneo, on the Mornington Peninsular Victoria, to determine if the addition of various organic amendments could increase and maintain soil organic carbon levels, and reduce requirements for the addition of inorganic fertilisers. The experiment was a randomised complete block split plot design, with four replicates. The experiment ran for the period of 5 crops in a broccoli – celery rotation, including 3 broccoli crops. Figure 7.1 shows the time and sequence of the crops grown. Organic amendments were applied as the main treatments and fertiliser rate treatments were the sub treatments. The Organic amendment where applied prior to transplanting of each of the broccoli crops. The organic amendments were applied approximately 1 week before transplanting and incorporated with a power harrow immediately following application, followed by beds forming. Lignite was only applied to the second and third broccoli crops because of availability. The rates at which organic amendments were applied are shown in Figure 7.1. The first of the three applications of Pinegro compost and composted chicken manure was much higher that subsequent applications, however, subsequent applications of all organic amendments targeted an application rate of 5 t/ha of carbon. Inorganic fertilisers were applied at full and half of standard grower rates for all broccoli crops in the experiment. Soil samples were collected to a depth of 10 cm at transplanting and harvest for each of the broccoli crops. The soil chemical analysis was only conducted on the main treatments.

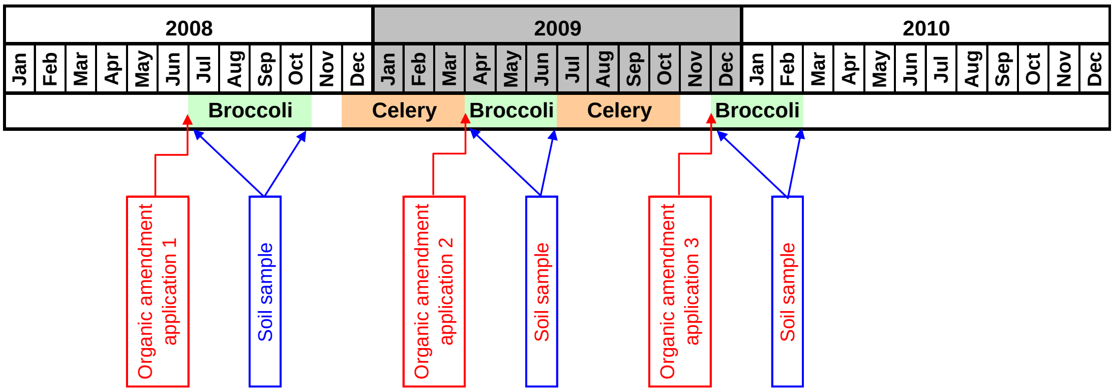


Figure 7.1 Time of year and sequence of crops grown in long-term experiment at Boneo.

Table 7.1 Organic amendment application rates for each of three applications for compost, chicken manure, silage and Lignite.

Treatment	Organic amendment application rate (t/ha) By application number and date 1 30/06/2008	2 24/03/2009	3 16/12/2009
Standard Grower Practice (SGP)			
Metham Sodium			
Pinegro Compost	64	18	19
Chicken manure	46	13	13
Silage	9	9	9
Lignite		7	7

7.4 Results and discussion

7.4.1 Organic amendments composition

Different organic amendments contain different amounts of carbon

Carbon (C) is the dominant element in organic matter (OM) and most organic amendments. Other elements include hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P) and sulphur (S). However the ratios of these chemical elements can vary greatly between different organic amendments. Additionally, organic amendments can contain inorganic minerals, including inorganic forms of nutrients and sand, silt and clay particles.

Table 7.2 shows the organic carbon concentration of the organic amendments used in this experiment. Compost had the lowest carbon concentration and Lignite had the highest. As a result of having different carbon concentrations, the amount of carbon applied in each of the organic amendments was not proportional to the total application rate (Figure 7.2). Although compost was applied at the highest rate, more carbon was actually applied in the composted chicken manure treatment. Despite a Lignite application of just 14% of the compost application, the Lignite carbon application equated to 35% of the compost carbon application.

Table 7.2. Organic carbon, organic nitrogen and C:N ratio of each organic amendment applied in experiments.

Organic amendment	Organic Carbon (% of dry weight)	Organic Nitrogen (% of dry weight)	C:N ratio
Pinegro compost	28	1.7	16.5
Composted chicken manure	38	3.2	12.0
Rye grass silage	58	2.1	27.7
Lignite	68	0.5	136.0

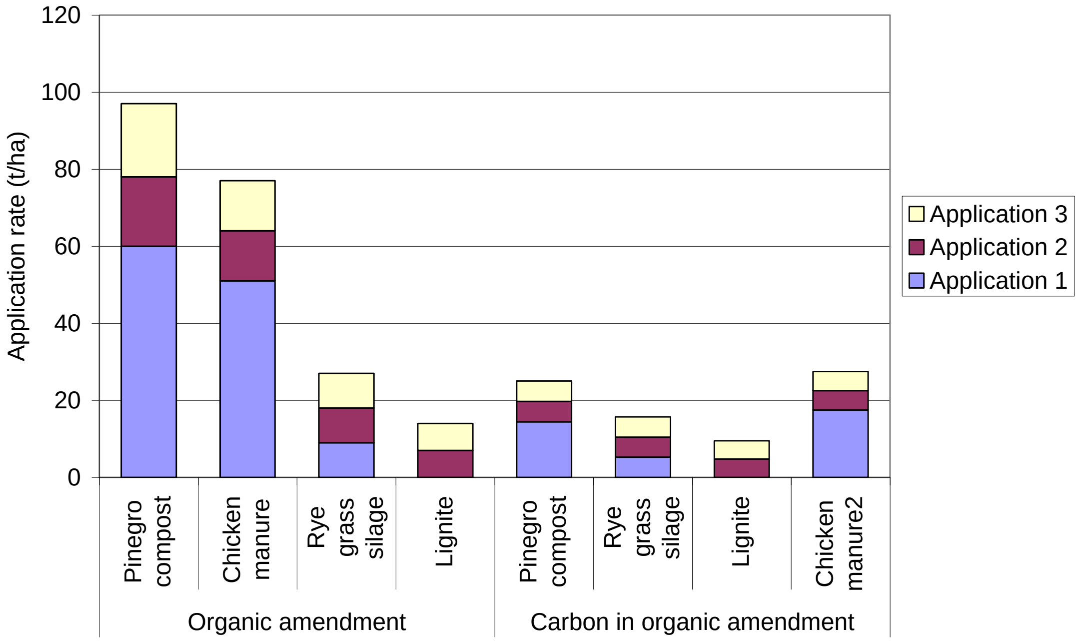


Figure 7.2. Organic amendment (Pinegro compost, composted chicken manure, rye grass silage and Lignite) application rates (t/ha) for each application and estimated quantity of carbon applied in each application.

Different organic amendments contain different types of carbon
The form of carbon varies between different organic amendments. This affects the rate at which the organic amendment decomposes and the function that it performs in the soil. Microorganisms decompose OM to obtain the energy and nutrient contained within it. However, the chemical composition of the organic matter determines the availability of the energy and nutrients, and therefore resistance to decomposition. As organic matter decomposes it becomes increasingly resistant to microbial

degradation. This occurs because the more resistant components of organic matter remain and accumulate in the soil following decomposition. Additionally, during decomposition microbes can modify the carbon form into more complex and resistant compounds, a process called “humification”.
Compost is the result of a managed decomposition process in which successions of aerobic micro-organisms break down and transform organic material into a range of increasingly complex organic substances, many of which are loosely referred to as humus (Paulin and O’Malley 2008). Consequently, composts such as the Pinegro compost used in this experiment are relatively resistant to microbial degradation. Much of the labile carbon in the original organic material has been consumed and modified during the composting process. Ryegrass silage and composted chicken manure are comparatively fresh and still contain high concentrations of more liable or degradable carbon compounds. Lignite, which is soft brown coal, has undergone the process of humification and coalification over millennia making it highly resistant to microbial degradation.

Carbon to Nitrogen ratio of organic amendments
The proportion of carbon relative to nitrogen (N) in OM is known as the carbon to nitrogen ratio or C:N. Microbes require sufficient N relative to C to decompose OM. In combination with the forms of carbon, the C:N ratio of an organic amendment gives an indication as to the ease with which it may be decomposed by microbes. In general, a lower C:N ratio results in more rapid decomposition. Table 7.2 shows the C:N ratio of the organic amendments used in this project. Of the amendments used, composted chicken manure has the lowest C:N ratio, and would therefore be most decomposable. Lignite has the highest C:N ratio and is considered the most resistant to microbial degradation.

7.4.2 Organic amendments and Total Organic Carbon (TOC)

Organic amendments can be effective in significantly increasing the amount of organic carbon in the soil, however the response in TOC is highly dependent on the nature of the organic amendment applied. Animal manures, green manures, silage and crop residues contain a large proportion of carbon that is ‘labile’, meaning it is more susceptible to decomposition by soil organisms. Whereas, composts and lignite contain increasing amounts of carbon in forms that are resistant to microbial decomposition. As a result three applications of composted chicken manure (totalling 30 tC/ha) did not maintain soil carbon levels any higher than three application of compost (totalling 27 tC/ha) or two applications of lignite (totalling 10 tC/ha).
The first of the three applications of compost (17 tC/ha) and chicken manure (20 tC/ha) were much higher than the second and third applications (5 tC/ha per application for both compost and chicken manure). For both additives, the initial application was able to significantly increase TOC levels relative to Standard grower practice (Figure 7.3). However, for both additives, TOC levels gradually declined even with the subsequent smaller applications of organic amendments.

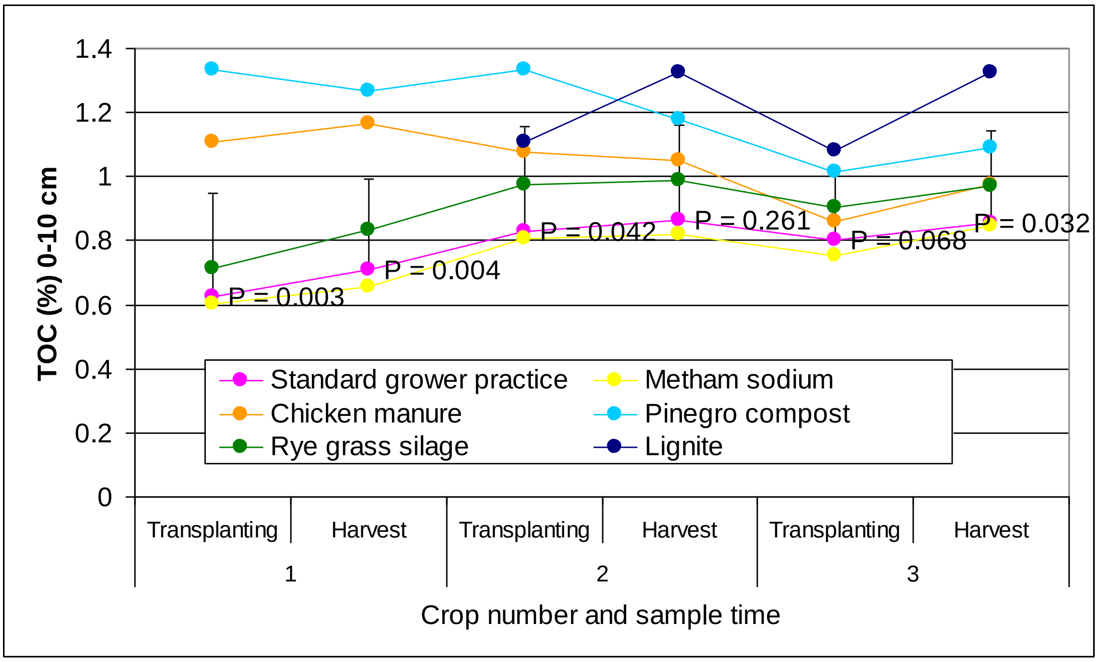


Figure 7.3. Total organic Carbon (TOC) concentrations in three broccoli crops, measured at harvest and transplant following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop. Error bars represent LSD (p=0.05) for each sampling time.

The reason for this lack of maintenance of increased soil carbon following the addition of chicken manure is illustrated in Figure 7.4, which shows soil CO_2 respiration at transplant and harvest for two of the three broccoli crops following the application of organic amendments (CO_2 respiration was not measured in the third broccoli crop). Soil CO_2 respiration gives an indication of the level of soil microbial activity. CO_2 respiration significantly increases following the application of composted chicken manure because it contains high concentrations of labile carbon compounds that provide a substrate or energy source for soil microbes. Compost and Lignite contain much less labile carbon compounds that are resistant to microbial degradation, and therefore there is little increase in soil respiration in response to the application of these compounds.

The more rapid decomposition of animal and green manures, although resulting in lower soil carbon values, has important benefits for the soil. It is the decomposition of OM that improves soil structure and releases plant nutrients (e.g. N) bound within it. Therefore, the organic amendment most appropriate for a particular situation will depend on the aim of the application. Less labile forms of carbon will build soil carbon, but do not drive biological processes, which is where you get benefits of disease suppression, nutrition, building of soil structure.

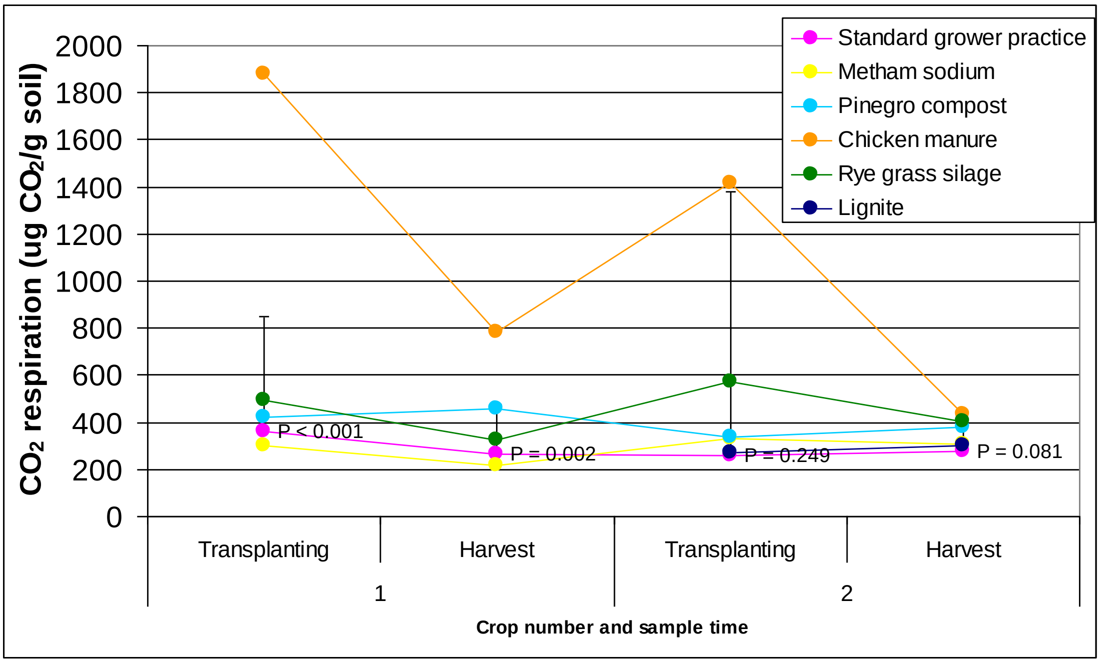


Figure 7.4. Soil CO_2 respiration of two broccoli crops, measured at harvest and transplant following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop. Error bars represent LSD (p=0.05) for each sampling time.

7.4.3 Organic amendments soil nitrogen fertility

Vegetables are often grown on sandy soils, and these soils commonly have inherently low nitrogen fertility. Soil organic matter, as well as containing considerable quantities of carbon (approximately 50-58%), also contain other important plant nutrients (N, P, S and K). As soil OM decomposes, these nutrients can be released in plant available forms. Therefore, building soil organic matter levels through the application of organic amendments can provide a slow release source of plant nutrients, particularly nitrogen.

Figure 7.5 shows the total organic nitrogen (TON) levels for the three broccoli crops at harvest and transplant following the application of organic amendments prior to transplanting of each crop. TON follows a similar trend to TOC levels shown above. The first of three applications of compost (17 tC/ha) and chicken manure (20 tC/ha), which was much higher than the second and third applications (5 tC/ha per application for both compost and chicken manure), significantly increase TON levels, however, TON levels then tended to decline even with the subsequent smaller applications of these organic amendments. This shows that the application of these organic amendments can increase soil nitrogen fertility, however, if organic inputs are not maintained, organic nitrogen fertility will decline over time and there will be a greater reliance on inorganic fertiliser nitrogen inputs.
Lignite and silage also tended to increase TON relative to SGP, however, this increase was not statistically significant.

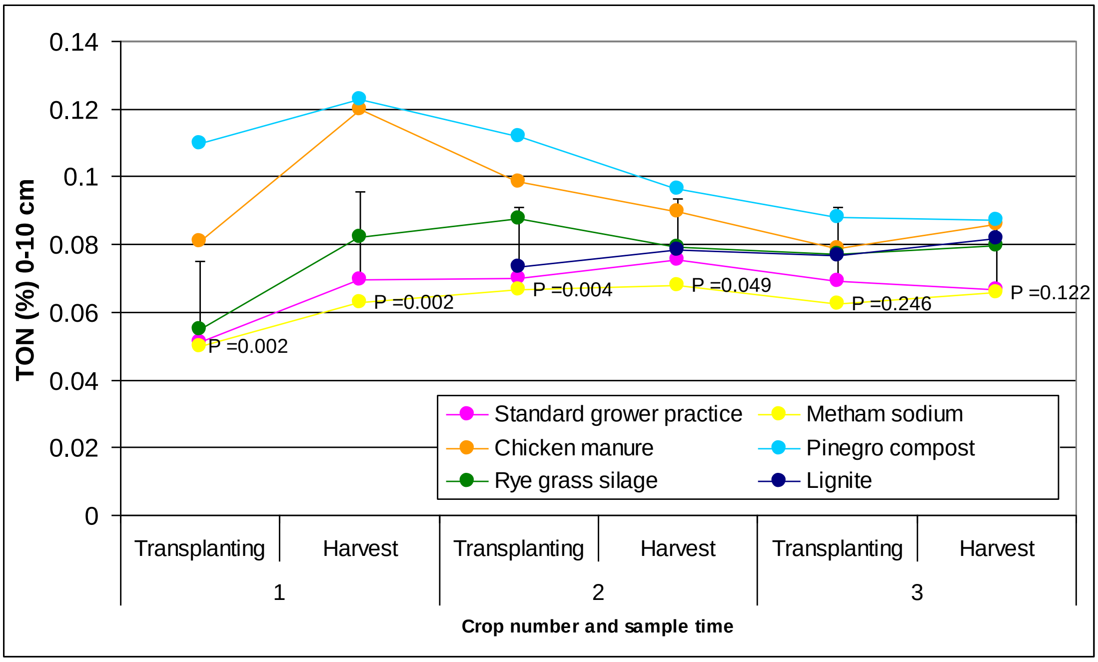


Figure 7.5. Total organic nitrogen (TON) concentrations in three broccoli crops, measured at harvest and transplant following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop. Error bars represent LSD (p =0.05) for each sampling time.

7.4.4 Organic amendments and soil C:N ratio

The carbon to nitrogen ratio of the soil gives an indication of soil fertility. Soils with a lower C:N ratio are more fertile, containing more nitrogen relative to carbon. As organic matter decomposes in soil with a lower C:N ratio, nitrogen is more likely to be released in plant available forms. In this experiment, application of all amendments other than lignite had little effect on the soil C:N ratio (Figure 7.6). The application of Lignite significantly increased the soil C:N ratio. This indicates that as Lignite decomposes nitrogen is more likely to be immobilised rather than released in plant available forms. However, the resistant nature of lignite means that it is likely to break down more slowly, reducing nitrogen immobilisation rates.

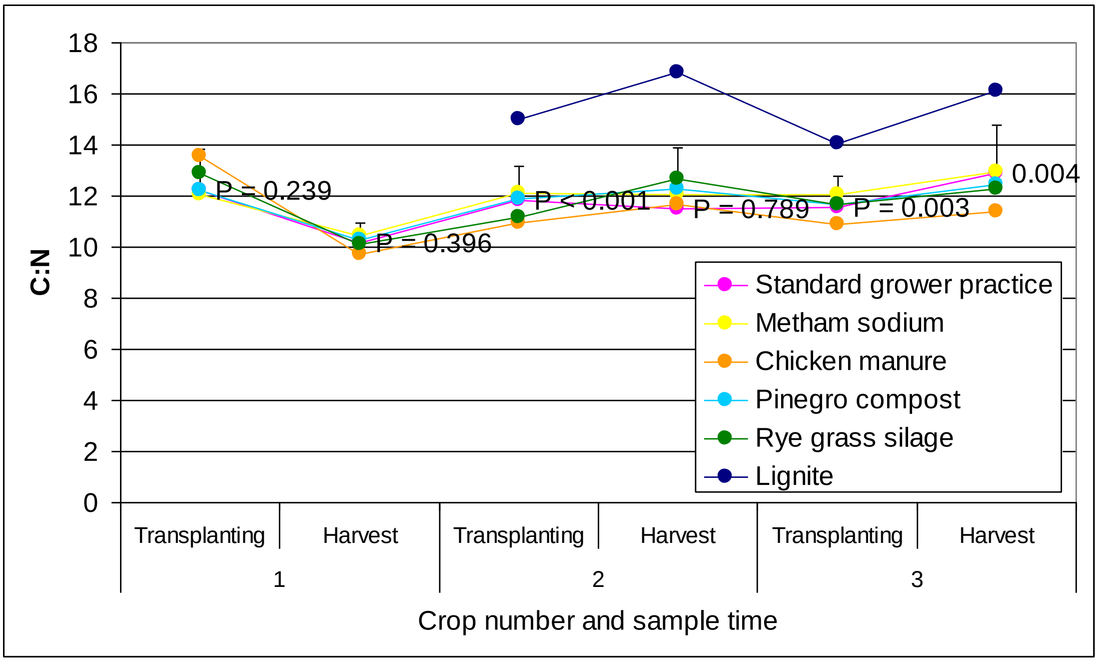


Figure 7.6. Soil C:N ratio in three broccoli crops, measured at harvest and transplant following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop. Error bars represent LSD (p=0.05) for each sampling time.

7.4.5 Organic amendments on total inorganic N

In vegetable production systems a large proportion of plant nitrogen requirements are satisfied by the application of inorganic nitrogen fertilisers. However, as many of these soils are sands, nitrogen applied in such a manner is susceptible to nitrogen leaching below the root zone. Organic amendments, composted chicken manure and compost, contain considerable concentration of nitrogen in both organic and inorganic forms. The inorganic forms provide an immediate source of plant nitrogen, while the organic forms provide a slow release nitrogen source as the organic matter decomposes. Figure 7.7 shows that the addition of both compost and composted chicken manure significantly increase soil inorganic nitrogen at transplanting, and in the case of chicken manure, maintained higher inorganic nitrogen levels until harvest. This would suggest that the crop is more evenly supplied with nitrogen. However, it must also be noted that inorganic nitrogen applied to the soil in composts and chicken manures is also susceptible to nitrogen leaching, which can have negative consequences for the environment. Nitrogen leaching was not measured under these systems.

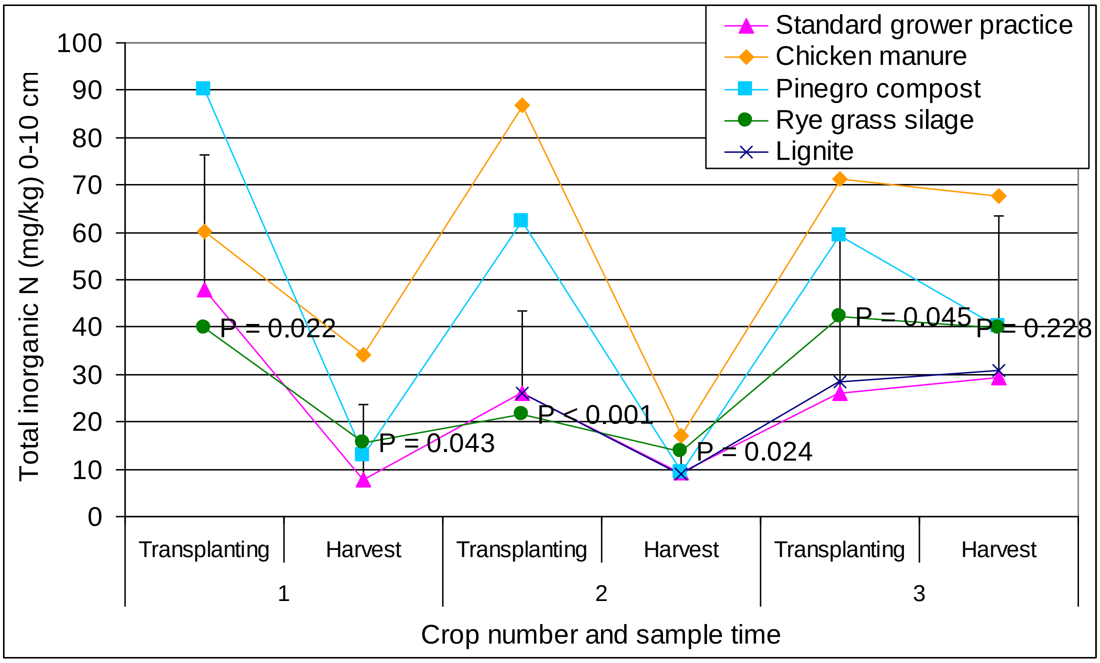


Figure 7.7. Soil total inorganic nitrogen in three broccoli crops, measured at harvest and transplant following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop. Error bars represent LSD (p=0.05) for each sampling time.

7.4.6 Organic amendments and plant available water capacity

Irrigation water has become a limited and valuable resource. Availability of good quality water and increasing water costs is an increasingly common issue faced by vegetable growers and improved water use efficiency has become a leading driver for improving soil health.
Soil organic carbon influences soil structure, which can in turn affect water infiltration, soil water holding capacity and plant available water capacity.
In this experiment soil water holding capacity was measured at transplanting and harvest following 2 applications of each of the organic soil amendments.

The application of Pinegro compost, chicken manure and lignite all significantly increased the water holding capacity (WHC) of the soil compared to SGP and metham sodium fumigation (Figure 7.8). Soils treated with these organic amendments had a higher WHC at both 10 and 40 kPa (0-10 cm). However, readily available water capacity (RAWC), the water stored in the soil that easily extracted by plants, is calculated to be the difference in WHC between these two pressures (10 and 40 kPa). Because the application of these organic amendments increased WHC at both of the pressures, there is no additional water available to the plants (Figure 7.8). In other words, although the application of these organic soil amendments increased the amount of water held by the soil, the additional water was held very tightly and therefore would not be available to the crop.

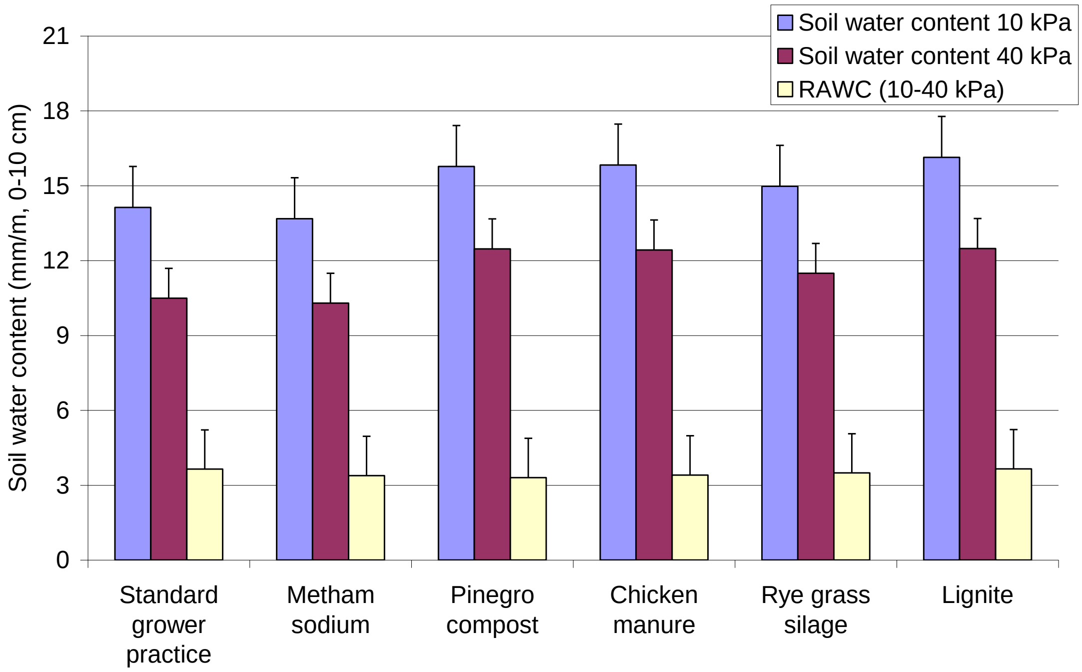


Figure 7.8 Average soil water content at 10 and 40 kPa and 'readily available water' content (RAWC), for 0-10 cm depth, of a sandy soil from Boneo, Vic, following two additions of organic amendments or fumigation. Error bars represent LSD (p=0.05) for each pressure range.

A laboratory experiment was established using the same soil type as in the field experiment to determine the effect of the application of compost at various rates on soil WHC and RAWC. Compost was added to soil from the field at rates equivalent to 0, 10, 50 and 100 t/ha. Disturbed soil cores were formed from the amended soil.
As with the field experiment, the addition of compost increase the WHC of the soil, with the WHC at 10 and 40 kPa significantly increasing with higher applications of compost. However, as with the field experiment, the addition of compost increased WHC at both pressures (10 and 40 kPa) and therefore actually decreased PAWC (Figure 7.9).

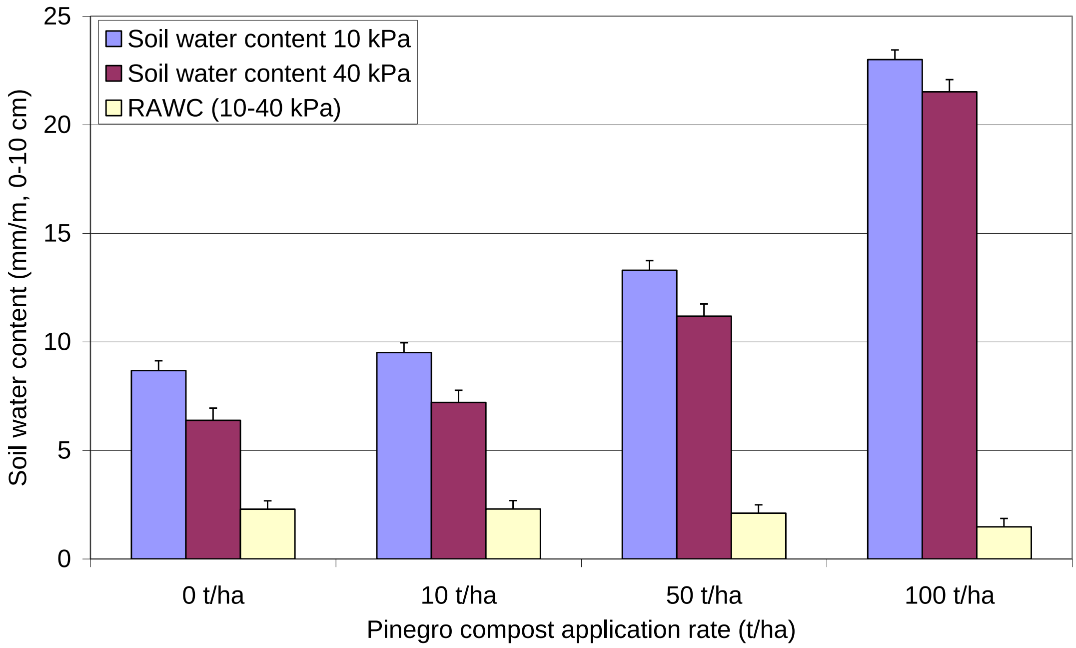


Figure 7.9. Soil water content at 10 and 40 kPa and 'readily available water' content (RAWC), for 0-10 cm depth, of a sandy soil from Boneo, Vic, following the application of Pinegro compost at various rates. Error bars represent LSD (p=0.05) for each pressure range.

Findings from these two experiments are contrary to common belief, that the application of organic soil amendments, and particularly compost, significantly increases both soil water holding capacity and plant or readily available water content. This work therefore needs to be expanded to include a wider range of organic soil amendments, application rates and soil types to determine the situations where the current findings are true.

7.4.7 Yield and fertiliser requirements

In this experiment, the application of half of the standard grower practice nitrogen fertiliser rates resulted in significantly lower yields in the first and second broccoli crops (Figure 7.10) and tended towards lower yield in the third crop. However, the application of all the organic amendments, except Lignite, was able to overcome this yield loss, resulting in broccoli yields that were statistically equal or greater compared to the standard grower practice, while using only half the rate of nitrogen fertiliser (Figure 7.11). With the exception of chicken manure, yield was further improved by the combination of both organic amendments and full nitrogen rates. In the first and third broccoli crops, there was a tendency for yields to decline with higher rates of nitrogen fertiliser combined with chicken manure.
Broccoli yields were generally lower in the second broccoli crop compared to the first and third crops, and yield response to all organic treatments was suppressed. However, the trends in yield response remained similar to the other two crops. The reason for this lack of response in the second crop is unclear, however may relate to the time of year when the crops were grown, or the broccoli cultivar grown. The second crop was grown over winter, while the first and third crops were grown in spring and summer, which may impact on nitrogen losses and supply from the soil.

While chicken manure increased yield and reduced nitrogen fertiliser requirements, it is also important to consider other environmental impacts. Nitrate leaching remains a risk when using chicken manure because organic nitrogen within it is readily mineralised releasing high concentrations of nitrate-N.

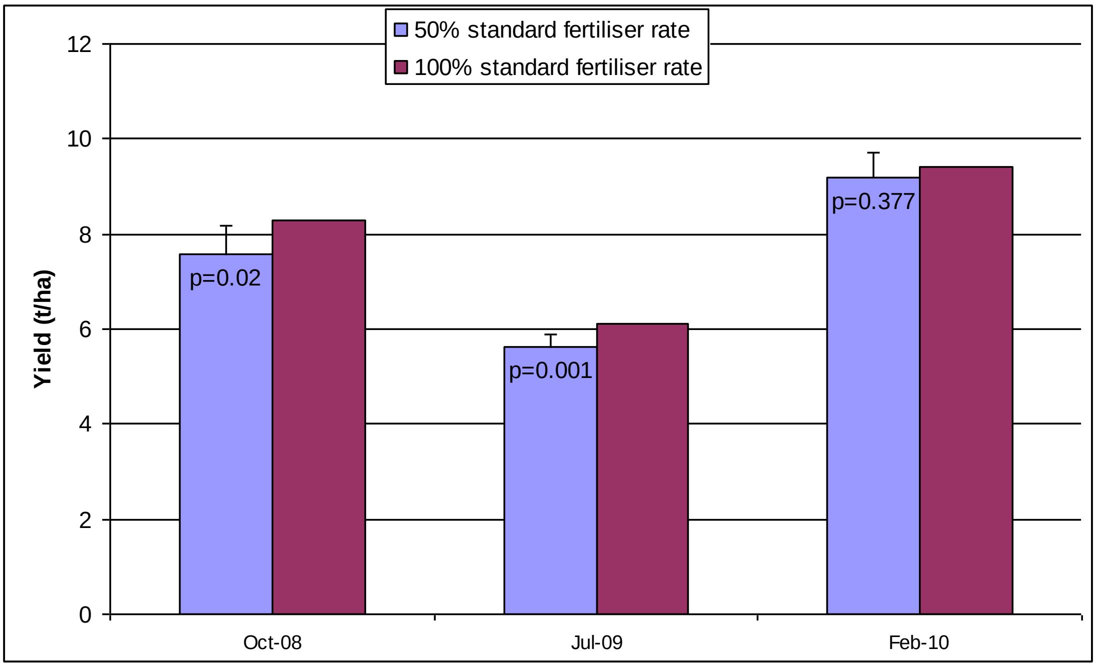


Figure 7.10. Yield of three broccoli crops with nitrogen fertiliser (Calcium nitrate) applied and 100% (128.8 kgN/ha) and 50% (64.4 kgN/ha) of standard grower practice. Error bars represent LSD (p=0.05) for each crop.

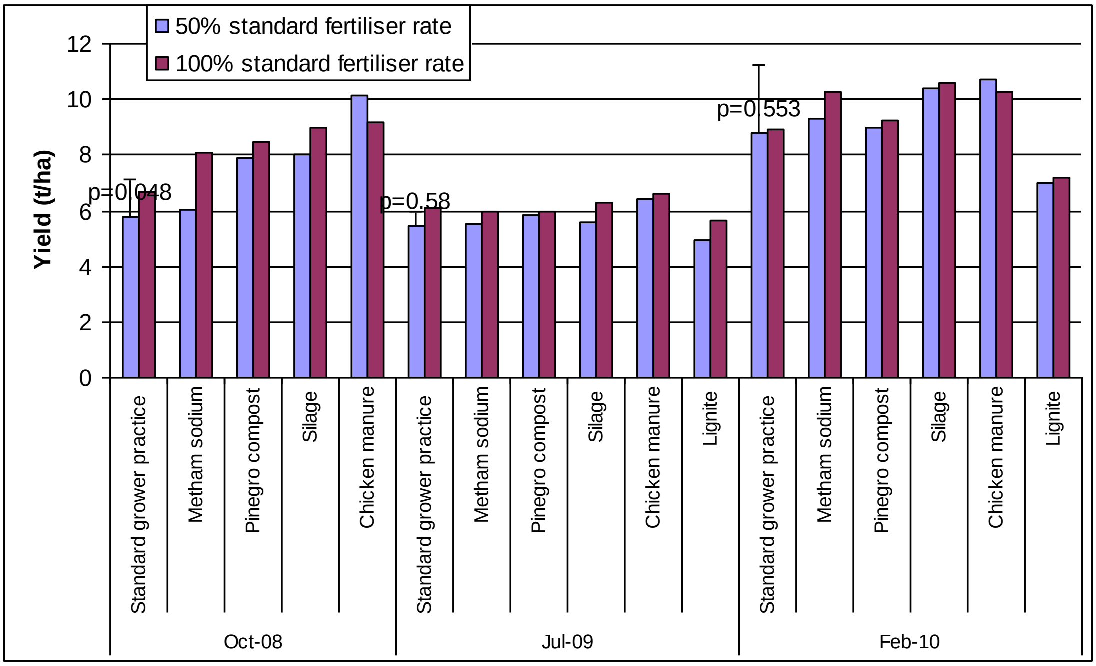


Figure 7.11 Yield of three broccoli crops following the application of organic amendments (Pinegro compost, composted chicken manure, rye grass silage and lignite) prior to transplanting of each crop, combined with nitrogen fertiliser (Calcium nitrate) applied and 100% (128.8 kgN/ha) and 50% (64.4 kgN/ha) of standard grower practice. Error bars represent LSD (p=0.05) for each crop.

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

8.1 Summary

- This study was undertaken to determine the changes in soil physical and chemical properties in adjacent paddocks that had be used for continuous vegetable cropping for a range of periods from zero to eight years.
- All paddocks were managed by the same farmer who used comparatively high levels of organic matter inputs compared to the local vegetable industry. This included retaining crop residues, growing green manure crops, and applying chicken manure.
- Despite the high level of organic matter returned, it was found that the paddocks that had been in vegetable production longer had lower soil organic carbon levels. 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 demonstrates that high levels of TOC can be established even in sandy soils under a suitable farming system.
- Phosphorous and copper were found to be 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.

8.2 Methodology

The study of soil organic carbon dynamics is difficult because changes in carbon level usually occur slowly. Short-term trials, therefore, do not show the long-term trends, and long-term trials are few and often do not have management systems relevant to current farmer practices.

To investigate the long-term effect of vegetable production on soil organic carbon and soil health, we took the approach of monitoring soil organic carbon (SOC) levels and a range of soil health indicators on four paddocks at a vegetable growing property on the Mornington Peninsula, Victoria. Each of the four paddocks had been under vegetable production for a different amount of time. One of the paddocks had yet to be developed for vegetable production at the start of the monitoring period (0 year paddock), one was in the first year of vegetable production (1st year paddock), one the third year of vegetable production (3rd year paddock), and one the seventh year (7th year paddock). The 1st, 3rd and 7th year paddocks were all adjacent to each other (Figure 8.1). The paddock under development (0 year paddock) was approximately 800 m from the other three paddocks.

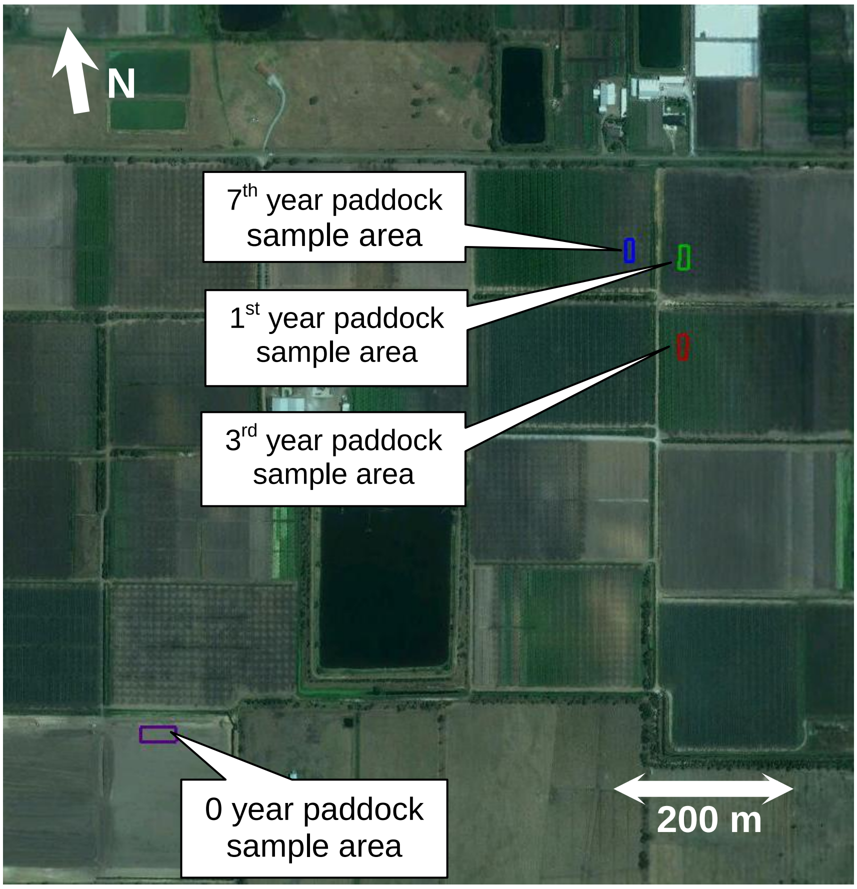


Figure 8.1 Satellite image showing the relative locations of the four paddocks use in the study.

The main assumptions of this study are that: i) all four paddocks represent similar growing conditions, ii) the history of all the paddocks prior to being developed for vegetable production was similar, and iii) all the paddocks have, or will have, similar treatment.

The soil at the site was Cranbourne sand, which can be described as a Pipey Podosol using the Australian Soil Classification system (Isbell 2002). The particle size analysis for each of the paddocks shows a very similar soil texture across all the paddocks (Figure 8.2). According to the farmer all the paddocks had a history of lightly grazed permanent volunteer pasture for more than five years prior to being developed, and a similar farming system has been used since land change to vegetable cropping. It is therefore believed that the assumptions of this study are reasonable. The three paddocks under vegetable production at the start of the monitoring period were sampled 9 times over a 1 year period, with each sampling approximately six weeks apart. The paddock not developed at the start of the monitoring period (0 year paddock) was only sampled twice, once while still under pasture (equivalent to the 5th sample time in the other three paddocks) and again after the paddock had been developed but before any vegetable crops had been grown (equivalent to the 9th or final sample time in the other three paddocks). Development of land for vegetable production on this property involved the removal of the top 30 cm of soil, laser levelling of the subsoil, respreading of the topsoil, followed by soil improvement before bed forming (Figure 8.3).

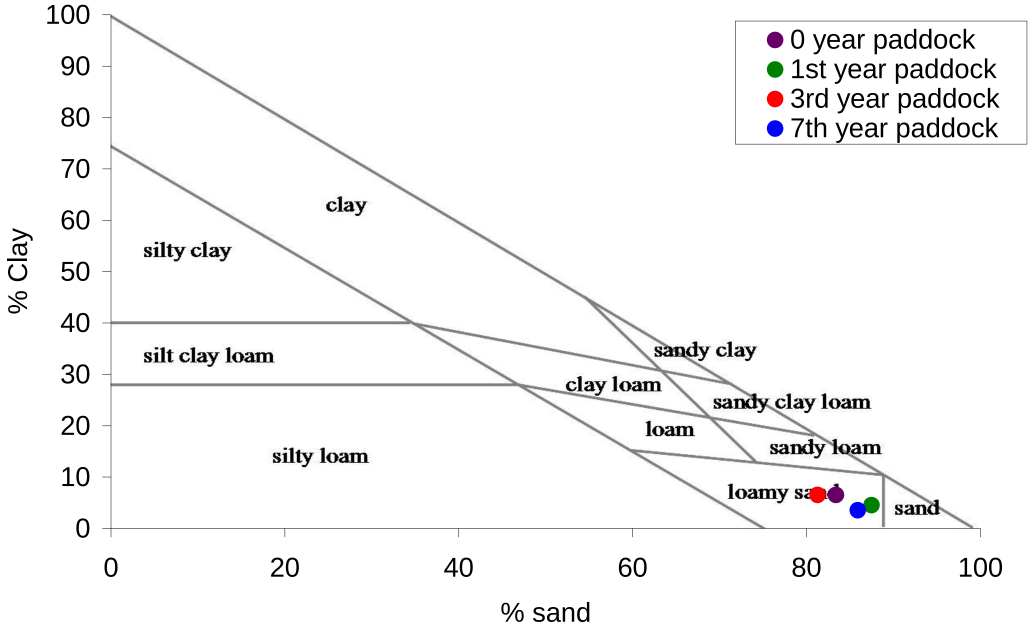


Figure 8.2 Australian Soil Texture Classification Triangle showing soil textures, and the sand and clay content (0-10 cm) of soil from each of the four paddocks.

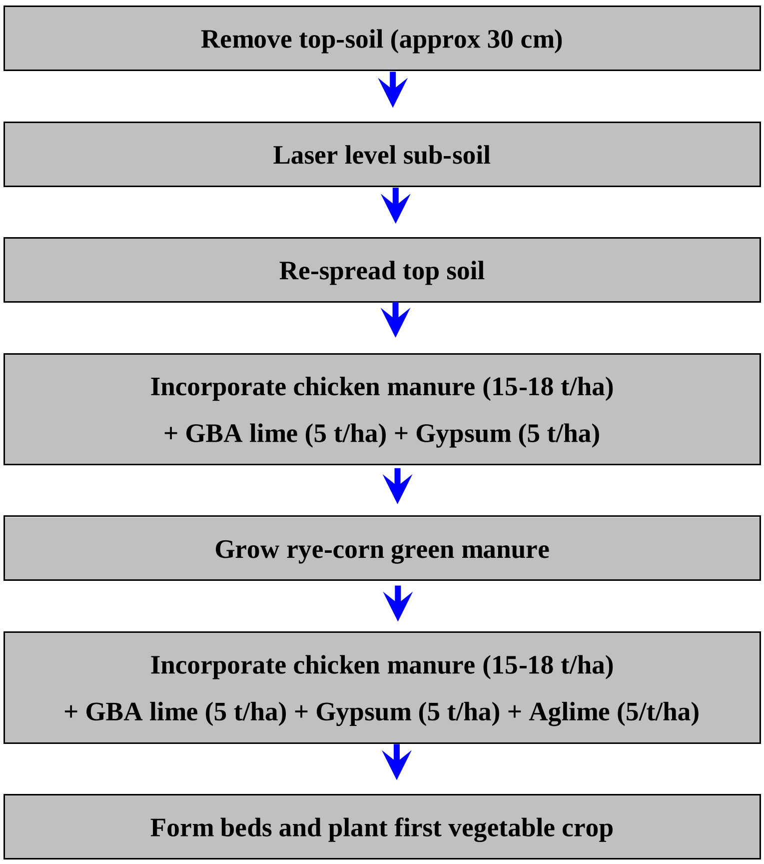


Figure 8.3 Schematic of the steps involved in developing a paddock for vegetable production.

The rotational histories prior to and during the monitoring period for each paddock is shown in Table 8.1. A more detailed description of the crop rotation for each paddocks and the timing of samplings are shown in Figure 8.4. At each sampling time a range of soil properties were measured which are outlined in Figure 8.2.

Table 8.1 Rotational history for each of the 4 paddocks in the study

	Paddocks and rotaion			
Year	0 year paddock	1st year paddock	3rd year paddock	7th year paddock
2001	Pasture	Pasture	Pasture	Cabbage Leek
2002	Pasture	Pasture	Pasture	Parsnips Rye green manure
2003	Pasture	Pasture	Pasture	Leek
2004	Pasture	Pasture	Pasture	Leek Kohlrabi Rye green manure
2005	Pasture	Pasture	Pasture	Leek Rye green manure
2006	Pasture	Pasture	Leek	Leek Kohlrabi Rye green manure
2007	Pasture	Pasture	Baby cos lettuce Rye green manure Leek	Leek Rye green manure
2008	Pasture	Pasture	Baby cos lettuce Parsnips	Leek Baby cos lettuce Rye green manure
2009	Pasture Paddock developed	Leek Baby cos lettuce Leek	Leek Endive	Endive Leek
2010		Parsnips	Rye green manure	Parsnips

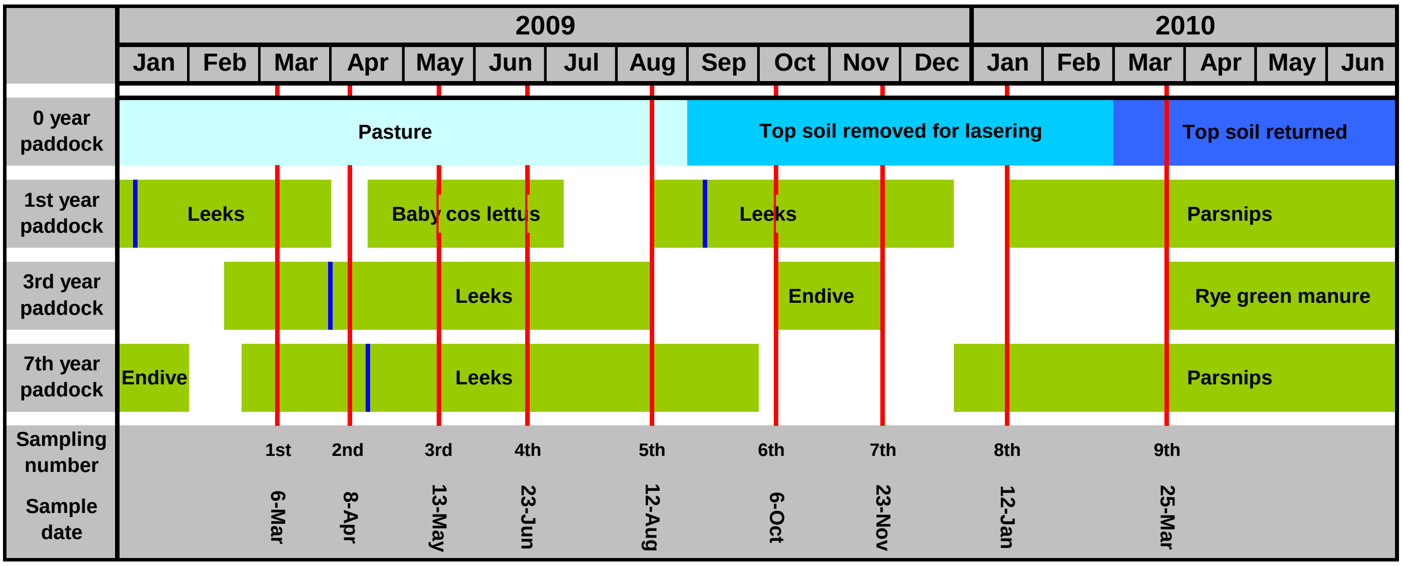


Figure 8.4 Crop sequence for each of the four paddocks for the duration of the monitoring period. The red lines (I) show the 9 sampling dates. The blue lines (I) show approximately when chicken manure was applied as a mulch on leek crops.

Table 8.2 Soil properties measured in each paddocks and timing of measurements.

Measurement	Paddocks	Sample times
Total organic carbon (TOC) – LECO	• 1st, 3rd & 7th year paddocks • 0 year paddock	• All • 5 and 9
Total organic nitrogen (TON) – LECO	• 1st, 3rd & 7th year paddocks • 0 year paddock	• All • 5 and 9
Water infiltration - Disk permeameter (-10 cm)	• 1st, 3rd & 7th year paddocks	• All
Bulk density	• 1st, 3rd & 7th year paddocks	• All
Chemical analysis: • Nitrate • Ammonium • Electrical Conductivity (measured as 1:5 extract converted to extract by multiplying by 13) • pH ($CaCl_2$ and water) • Exchangeable cations (Ca, Na, Mg, K) • Sum of four cations • Available K • Available P (Olsen) • Available S • DTPA extractable trace elements (Cu, Fe, Mn, Zn)	• 1st, 3rd & 7th year paddocks	• 1

8.3 Results and discussion

8.3.1 Total organic carbon

This study demonstrates a pattern of decreasing soil organic carbon (SOC) the longer a paddock is under vegetable production. However, this pattern is complicated by differences between the two soil depths measured (0-10 cm and 10-30 cm). The total organic carbon (the measure of SOC) for each paddock at the start and the end of the monitoring period, for the two depth ranges (0-10 and 10-30 cm) and the average (0-30 cm) is shown in Figure 8.5.

Prior to vegetable production all of the paddocks were under long-term (>5 years) permanent pasture. This pasture system had negligible soil disturbance which enables soil organic carbon to accumulate in the surface soil. This was demonstrated in the ‘0 year paddock’ which had a TOC concentration of about 5% in the top 10 cm while only 1.4% in the 10-30 cm depth range (Figure 8.5). These soil organic carbon levels would be considered high for the climate and sandy soil texture. Contributing to this is also likely to have been the high organic matter returns to the soil associated with grazing of the pasture.

The conversion of pasture to vegetable production resulted in considerable redistribution of organic carbon down the soil profile. This is not unexpected as the development of land for vegetable production on this property involved the removal of the top 30 cm of soil, laser levelling of the subsoil, and respreading of the topsoil, resulting in considerable, although not total, mixing of soil in the top 30 cm. When averaged across both depth ranges the TOC in the ‘0 year paddock’ decreased by a small amount from the start to the end of the monitoring period, suggesting that the mixing of soil did not, in itself, cause a great loss of soil organic carbon, although it may initiate further losses with time.

The more years a paddock has been in production, and therefore the number of times the top 30 cm of soil have been mixed, the less difference there is between the TOC levels in the 0-10 and 10-30 cm layers. This is illustrated in the regression curves fitted across all 4 paddocks which show that TOC rapidly declines in the 0-10 cm range in the first couple of years, while it also rapidly increases in the 10-30 cm depth range during the same time. After three years since the land change from pasture, the TOC levels in the two depth ranges converge to approximately 2.0% across the whole 0-30 cm depth range.

The average TOC value over the entire 0-30 cm depth range illustrates a pattern of slow decline over the first three years, with a gradually increasing rate of decline in TOC as the number of years in production increases. The regression curve does not suggest that an equilibrium value has been reached after 8 years of vegetable production, but rather that the decline in TOC is continuing at the same, or increasing, rate. The average rate of decline from the ‘0 year paddock’ to the ‘7th year paddock’ over the full 0-30 cm depth range was 0.19% per year. The average rate of decline from the ‘3rd year paddock’ to the ‘7th year paddock’ over the full 0-30 cm depth range was 0.25% per year.

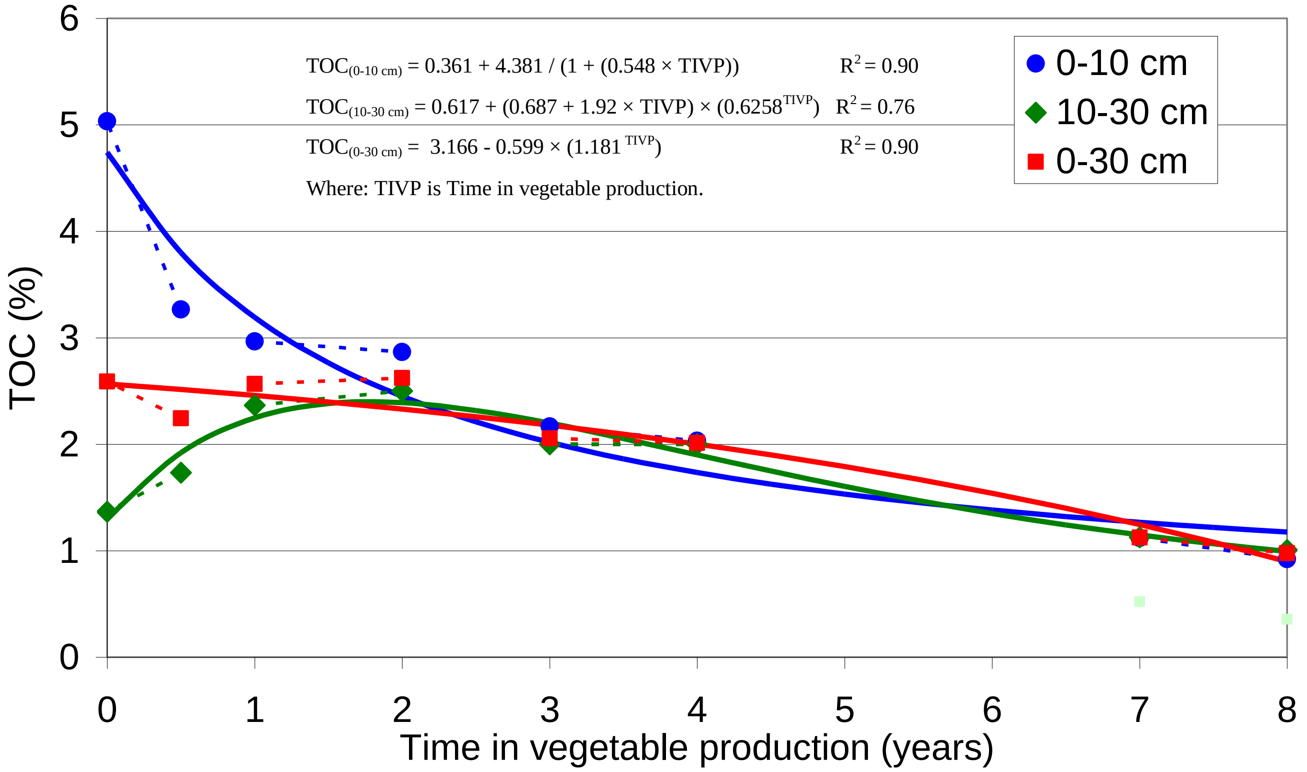


Figure 8.5 TOC levels for the 0-10, 10-30 and 0-30 cm depth ranges, at the start and end of the monitoring period for 1st, 3rd and 7th year scenario paddocks and 5th and last sampling time for the 0 year paddock. Dotted lines connect measurements in the same paddock for a particular depth.

The TOC (0-10 cm and 10-30 cm) values for all nine sampling times in each of the paddocks with crops growing shows that within each of the paddocks there was some in-season variability in TOC (Figure 8.6). This variability tended to be more pronounced the lower the number of years the paddock had been in production. There were some peaks in TOC in the winter/spring period and decrease in summer, which might be associated with temperature effects on the microbial populations. This variability reinforces the need to have measurements that span a long time period in order to gain a true indication of trends in TOC.

For the 1st and 3rd year scenario paddocks, the decline in TOC over the 12 month monitoring period was not as great as may have been expected from the decline in TOC between different paddocks. The reason for this can not be completely determined from this study, and reinforces the need to continue long-term monitoring of these paddocks to ascertain whether this is due to site, treatment, or random effects.

Although there is a pattern of declining TOC with increased years of vegetable production, the original TOC level, from the paddock in the long-term, lightly grazed pasture, may be considered high for such sandy soils. It therefore may be unreasonable to expect any crop production system to maintain the original TOC level found in the pasture site. It is well documented that there is likely to be an associated decline in aggregate structure for soils that contain a larger proportion of clay, when

TOC levels fall below 2% (O'Halloran *et al*., 2009). It is far less clear, however, what might be the soil health problems in such sandy soils when TOC levels fall below 2%, but it is probably reasonable to suppose that it would be beneficial if the vegetable farming system could be modified, possibly through the reduction in tillage, to prevent or reduce the declining TOC compared to a pasture system.

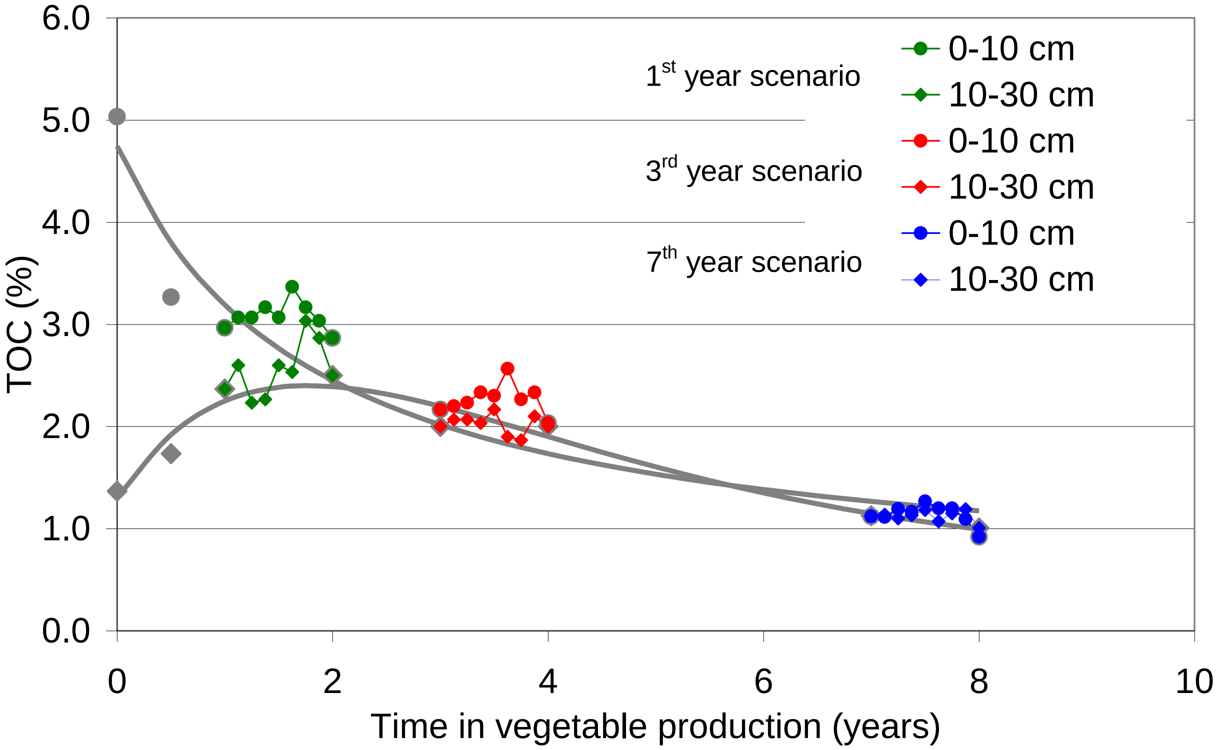


Figure 8.6 TOC levels for the 0-10 and 10-30 depth ranges, at all nine sample times for the 1st, 3rd and 7th year scenario paddocks, and 5th and last sampling time for the 0 year paddock.

8.3.2 Total organic nitrogen

The majority of soil nutrients are tied up in complex organic forms within the soil organic matter (SOM). To enable these nutrients to become plant available, microorganisms are required to breakdown the SOM and mineralise the nutrients into soluble forms that are suitable for plant uptake. In this way decomposition of SOM is essential for the cycling of plant nutrients.

Total organic nitrogen (TON) is a measure of the nitrogen contained within SOM. In the current study, differences in TON, as expected, followed a very similar pattern to those of TOC. TON accumulated in the surface soil of the pasture paddock (0 year paddock) and was redistributed down the soil profile following development of this land for vegetable production (Figure 8.7). In the 1st, 3rd and 7th year paddocks TON had been extensively homogenised and TON concentrations were similar in the 0-10 and 10-30 cm depth ranges.

One marked difference to the TOC data is that there was a more pronounced decline at each paddock in TON from the start to the end of the study. This decline in each paddock over the year means that the individual paddock responses follow more closely the regression curves fitted across all 4 paddocks than the TOC data. This might be because the nitrogen rich SOM that breaks down over one year makes up a larger proportion of the TON, than it does of the TOC, making it a more sensitive measure.

The continual decomposition of SOM and release of nitrogen in plant available forms has important production benefits for these paddocks. However, the decline in TON levels with increasing years of production means that the natural fertility of these soils is being considerably depleted, with the consequence that in future years there will be a need for greater reliance on fertiliser inputs to meet crop nitrogen requirements.

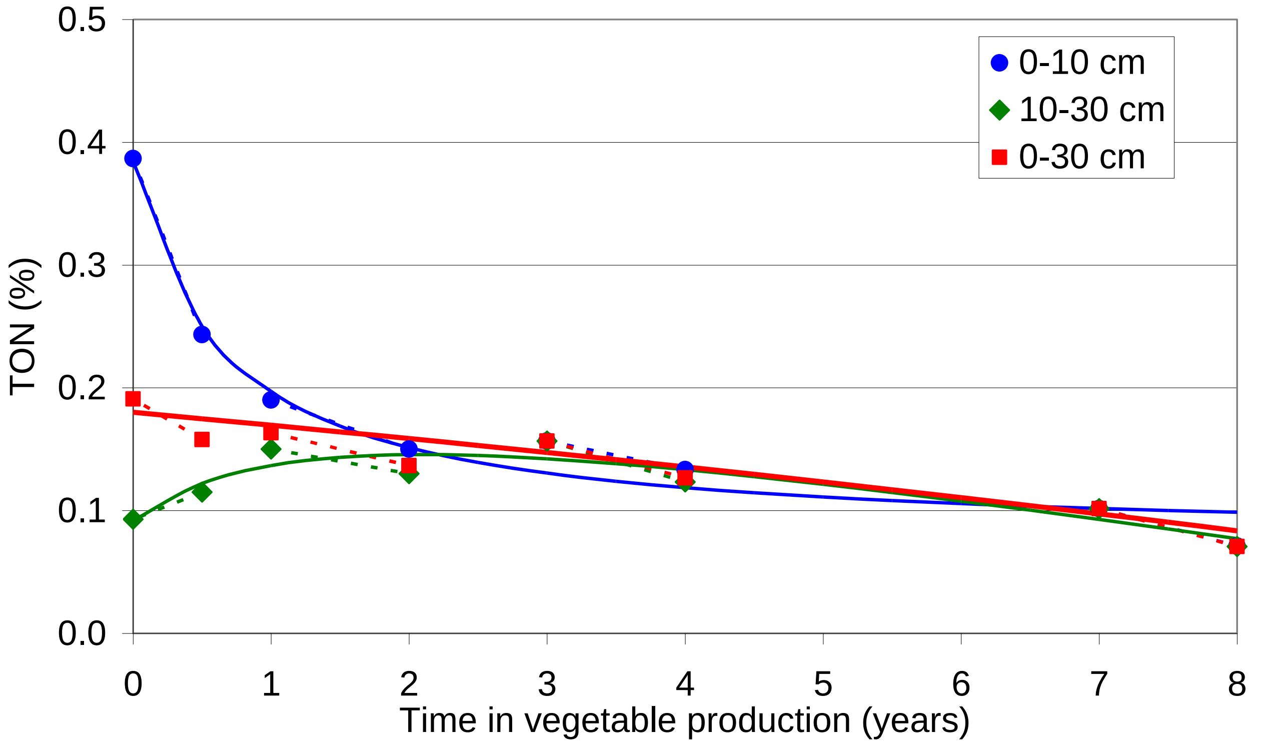


Figure 8.7 Total organic nitrogen levels for the 0-10, 10-30 and 0-30 cm depth ranges, at the start and end of the monitoring period for 1st, 3rd and 7th year scenario paddocks and 5th and last sampling time for the 0 year paddock.

8.3.3 Soil chemical properties

A range of soil chemical properties (Table 8.2) were measured at sample time 1 to determine the fertility of each of the paddocks. A number of these properties appeared to show little change with time under vegetable production (data not shown). These include pH_{water} (~6.8) and pH_{CaCl2} (~6.2), exchangeable cations (Ca, Na, Mg, K), and the sum of these four cations. Changes in these properties over time are more likely to have been influenced by applications of lime and gypsum. The trace elements Manganese (Mn) and Zinc (Zn) were also consistent with time in vegetable production.

There were a number of soil chemical properties, however, that showed either a decreasing or increasing pattern with the number of years since the start of vegetable production. These are outlined in more detail below, however, the data is only for the 0-10 cm depth range therefore some of the changes in chemical properties may be the result of further mixing of the soil layers, especially between the 1st and 3rd year paddocks.

8.3.4 Electrical conductivity (ECe)

There is a pattern of decreasing ECe with increased time in vegetable production (Figure 8.8). This would be expected under an irrigated system, with the continuous irrigation flushing soluble salts down the soil profile with time. In the 1st year paddock ECe was at a level of 5-6 ds m^{-1}. At this level it may harmful to vegetable crops, for example FAO guidelines suggest that for lettuce an ECe of 5.1 can result in a 50% potential yield loss (Ayres *et al*. 1976). ECe was lower in the 3rd year paddock, but still above recommended levels for most vegetable crops. The 7th year paddock had the lowest ECe, which by FAO guidelines would result in 0-10% potential yield loss in lettuce.

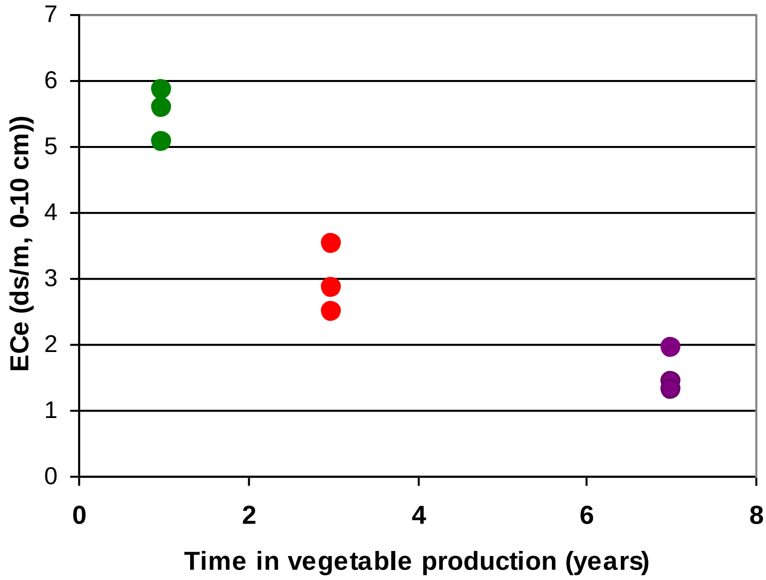


Figure 8.8 Electrical conductivity (ECe) of the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

8.3.5 Nitrogen (N)

There was a pattern of declining plant available nitrogen (nitrate) over time (Figure 8.9). This could be a result of a decline in soil organic matter. As SOM decomposes it releases nitrogen as nitrate. This nitrogen could have been removed in produce or leached below the root zone in paddocks that had been under vegetable production for longer. Newer paddocks are likely to have higher natural fertility, therefore a greater ability to supply crop nutrients and a more even supply of nutrients throughout the season. Paddocks that have been under vegetable production for longer are likely to have a greater reliance on inorganic or organic fertiliser inputs to meet crop nitrogen needs.

Figure 8.9 Nitrate measurements for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

8.3.6 Available Potassium (K)

Available potassium levels were high in all three paddocks (Figure 8.10). Available potassium was lower in paddocks that had been under vegetable production the longest. This is likely to occur due to removal of K through harvested product removal.

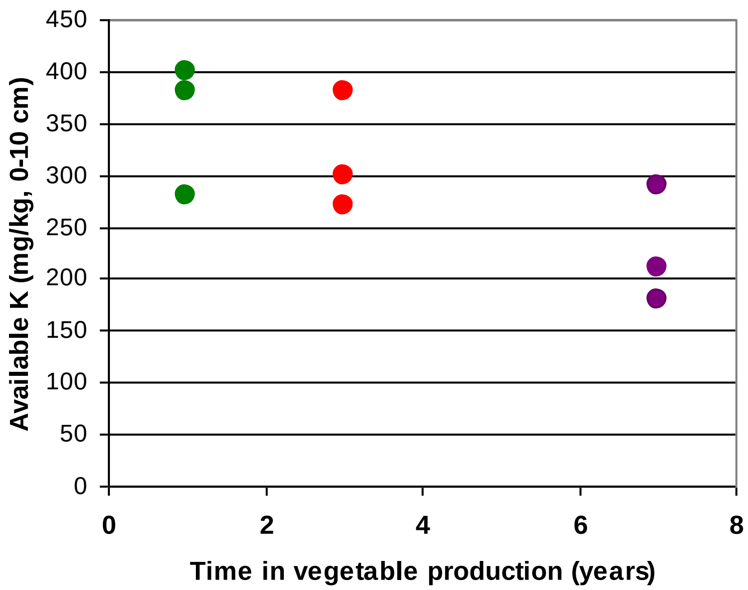


Figure 8.10 Available potassium for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

8.3.7 Sulphur (S)

Available S shows a pattern of reducing the longer the paddock is under vegetable production (Figure 8.11). This is common where high-analysis phosphatic fertilisers are used, as these contain low levels of sulphur. Sulphur levels are excessive in the newer paddocks, but are at acceptable levels in the 7th year paddock.

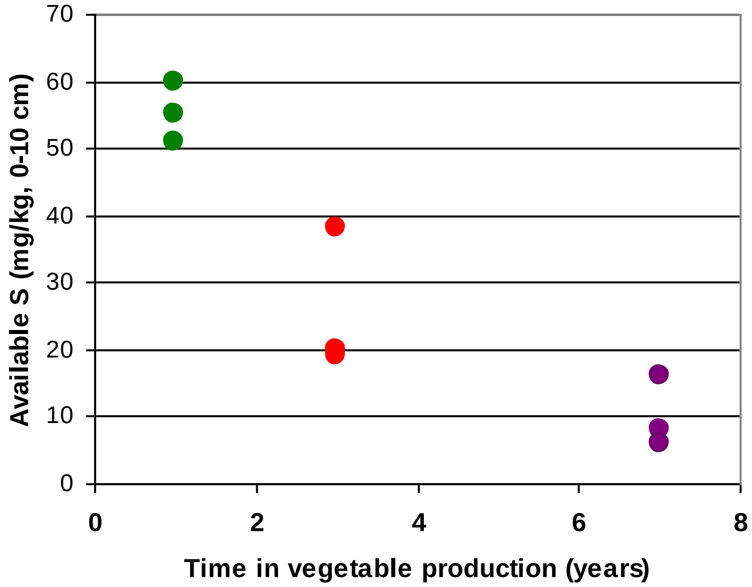


Figure 8.11 Available sulphur for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

8.3.8 Phosphorous (P)

Unlike most of the other elements, phosphorous is higher in the paddocks that have been in vegetable production for the longest (Figure 8.12). This is indicative of a good P fertiliser history which can result in a build up of P in the soil. P levels are high in all paddocks and excessive by the 7th year in production. In this situation there is a potential for P loss in water runoff and associated offsite impacts. There is potentially an opportunity to reduce fertiliser inputs in these paddocks and draw on P reserves in the soil.

Figure 8.12 Olsen phosphorous for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from 3 locations within each paddock.

8.3.9 Trace elements

Like phosphorous, copper (Cu) tends to accumulate in soil overtime and was higher in paddocks that have been in vegetable production for longer (Figure 8.13). Copper levels were acceptable in all three paddocks. Iron levels were lower in paddocks that had been under vegetable production for longer (Figure 8.14).

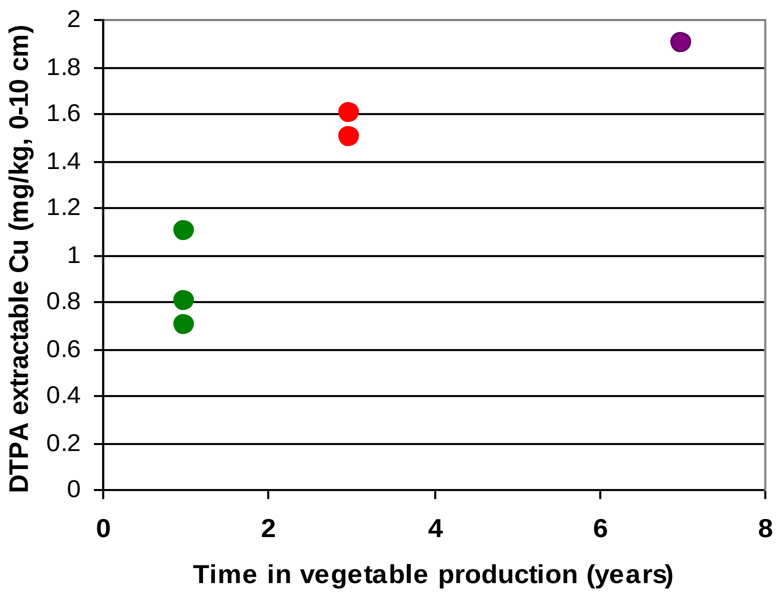


Figure 8.13 DTPA exchangeable Copper for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

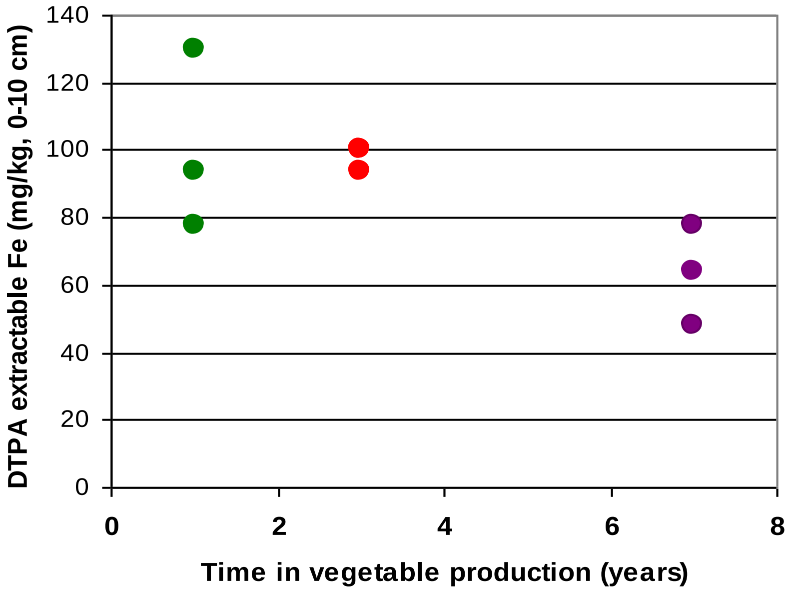


Figure 8.14 DTPA exchangeable iron for the 1st, 3rd and 7th year paddock, at sample time 1. Measurements are from three locations within each paddock.

8.3.10 Water infiltration

Infiltration plays an essential role in efficient water use, for both rainfall and irrigation. Adequate water infiltration reduces irrigation water requirements by reducing runoff and good redistribution of water within the soil can minimise evaporation by enabling water to penetrate deeper into the soil profile. These effects in turn reduce the amount of water used and pumping costs, and potentially reduce erosion, nutrient losses, and other offsite impacts.

Water infiltration rate is a function of soil texture, soil structure, and soil structural stability. Sandy soils are more porous and therefore have higher infiltration rates than clay soils. Soils with better soil structure have more and larger interconnected pores which also helps water flow. However, it is important that soil structure remains stable when the soil is wet to prevent collapse of the soil and greatly decreased infiltration. Both soil structure and structural stability are affected by soil organic matter levels. SOM provides the energy and nutrients for soil microorganisms which build and stabilise soil structure and SOM itself also binds and stabilises soil structure.

Water infiltration rates varied greatly between sampling times within each paddock, and three main factors were observed to influence infiltration rates across all three paddocks. These were:

- Cultivation
- Time in vegetable production
- Soil surface treatment

8.3.11 Cultivation

Cultivation had a large apparent impact on infiltration rate which is immediate but short lived. The infiltration response to cultivation was dependent on the water content of the soil when cultivated. In all three paddocks of the study, when the soil was cultivated dry (less than 50% of water holding capacity) the infiltration rate was substantially higher than when the soil was cultivated wet (greater than 50% of water holding capacity) (Figure 8.15). However, in the weeks following cultivation infiltration rates declined rapidly. In the 3rd and 7th year paddocks the consequence of cultivating wet was to reduce the infiltration rate to lower than the irrigation rate, with the result that there is likely to be greater runoff from these paddocks.

8.3.12 Time in vegetable production

During the initial period following cultivation (20 days) the infiltration rates obtained on the 1st year paddock were higher than those found in the 3rd and 7th year paddocks (Figure 8.15). Later in the crop (> 20 days) there was no apparent difference in infiltration rate between the 1st and 3rd year paddocks, but the 7th year paddock had a lower infiltration rate than both of them.

8.3.13 Soil surface treatment

Soil surface crusting, or sealing, is an issue on this farm. This crusting is caused by the breakdown of soil structure during irrigation due to water droplets impacting the soil surface. To study the effect this crusting has on infiltration rate, five comparisons were made, at various times during the study on the 3rd and 7th year paddocks, between infiltration rate with the crust intact and infiltration rate with the crust removed by hand. In all cases the crust had the effect of reducing the water infiltration rates (Figure 8.16, Figure 8.18).

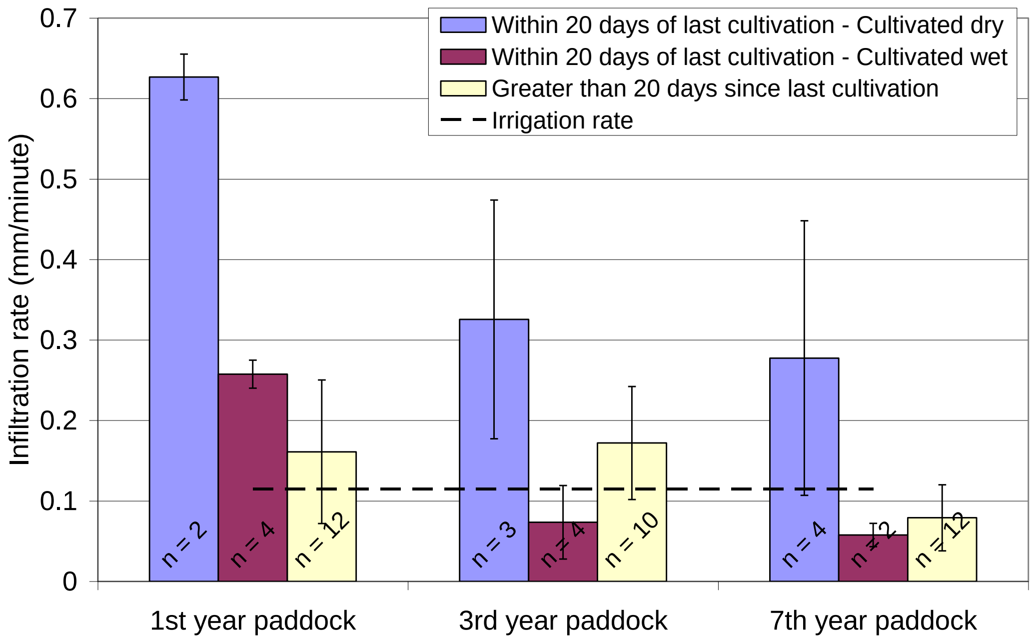


Figure 8.15 Equilibrium water infiltration rate (average infiltration rate >20 days after cultivation), average water infiltration rate of soils cultivated wet (> 50% of water holding capacity by hand feel) and soil cultivated dry (< 50% of water holding capacity by hand feel), within 20 days, for the 1st, 3rd, and 7th year paddocks.

The grower in this study routinely applies chicken manure at approximately 6 t/ha as a surface mulch when growing leeks, to physically protect the soil surface from irrigation and water droplet impact, and thus reduce surface crusting (Figure 8.17).

This mulch is normally applied about 6 weeks after transplanting. No other crops received this mulch due to management difficulties. Figure 8.18 shows the infiltration rates measured at three times in each of two consecutive crops in the ‘1st year paddock’. The first crop was a baby cos-lettuce without surface mulch, and the second crop was leeks with a mulch applied between the first and second infiltration measurements. Infiltration rates decline to a much lower level in the baby cos-lettuce crop, probably due to the surface mulch preventing soil crust formation in the leeks. Although a crust can form before the mulch is applied, it was observed that the mulch also increased worms and other soil organisms’ activity, which actively broke down initial crust formation.

Further work is needed to quantify the impact of these factors across a wider range of soil types and management systems, and whether the length of time in vegetable cropping or the soil TOC level are important factors.

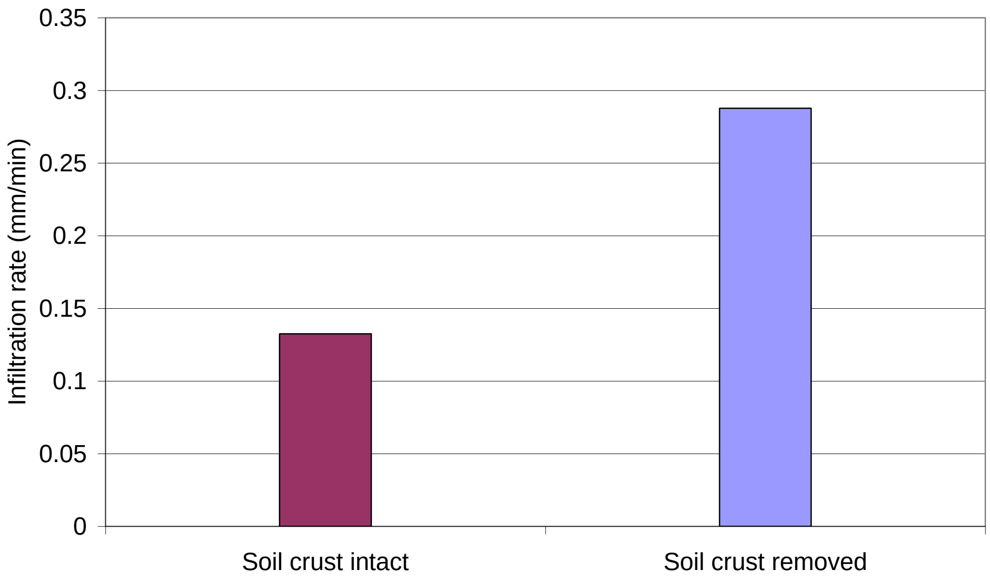


Figure 8.16 Infiltration rates with soil surface crust left intact or soil surface crust removed at various sample times for the 3rd year paddock and 7th year paddock.

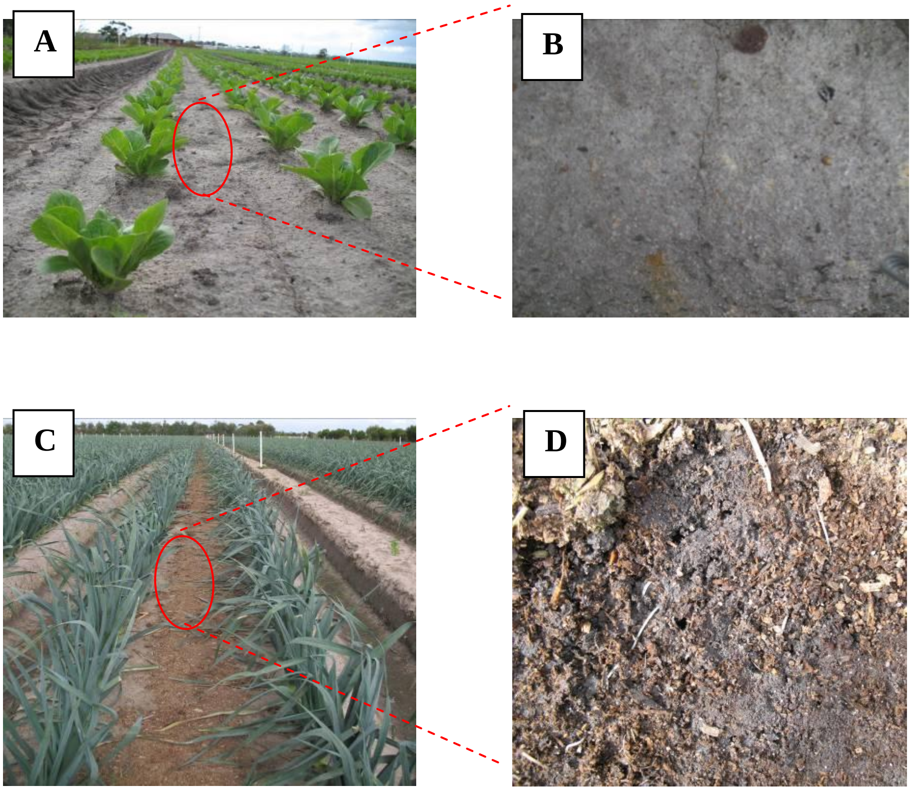


Figure 8.17 Baby cos-lettuce with no surface mulch (A) resulting surface crusting or sealing (B). Leek crop with chicken manure mulch applied between crop rows (C). Chicken manure mulch removed showing macropores formed by worms and other soil microbes (D).

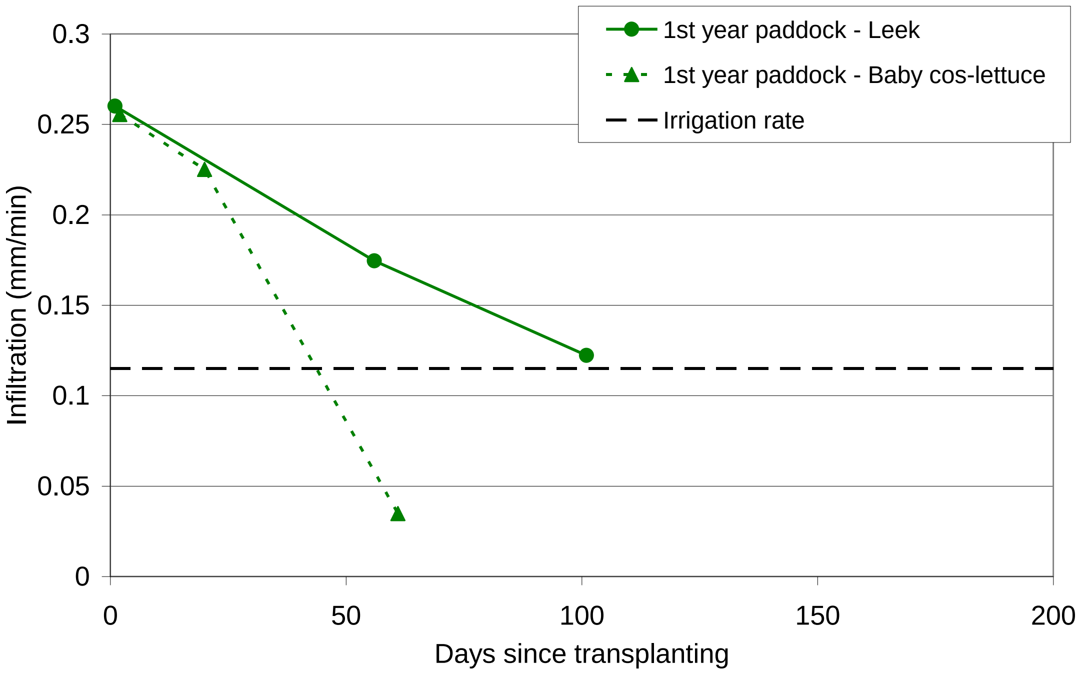


Figure 8.18 Infiltration rates at various stages after transplanting of leeks and baby cos-lettuce (1st year paddock).

8.3.14 Bulk density

Soil bulk density is a common measure of soil physical condition. As soil structure improves, there is an increase in the number and size of soil pores (air spaces), and as a result, bulk density decreases. Soils with low bulk density generally are capable of storing more plant available water, provide better aeration for plant roots and soil microbes, and pose less resistance to root growth and seed germination.

For the paddocks in this study extensive tillage is used which maintains a low soil bulk density. Following tillage, bulk density tends to increase over time (Figure 8.19), however, bulk density remained within an expected range for all paddocks at all times in this study.

Bulk density tended to be lowest in the 1st year paddock and remained lower than other paddocks for any given time after transplanting. At transplanting the 1st year paddock had a similar bulk density to that of the 0 year paddock in pasture (1.06). Bulk density was higher in the 0 year paddock following land forming (1.25), and this is probably due to the high amount of trafficking involved in re-spreading and levelling the top soil.

Bulk density also varied between crops. In all paddocks, bulk density tended to be lowest in leeks. This is likely to be because the transplanting of leeks does not involve a press-wheel which compacts soil around the seeding to improve seedling-soil contact.

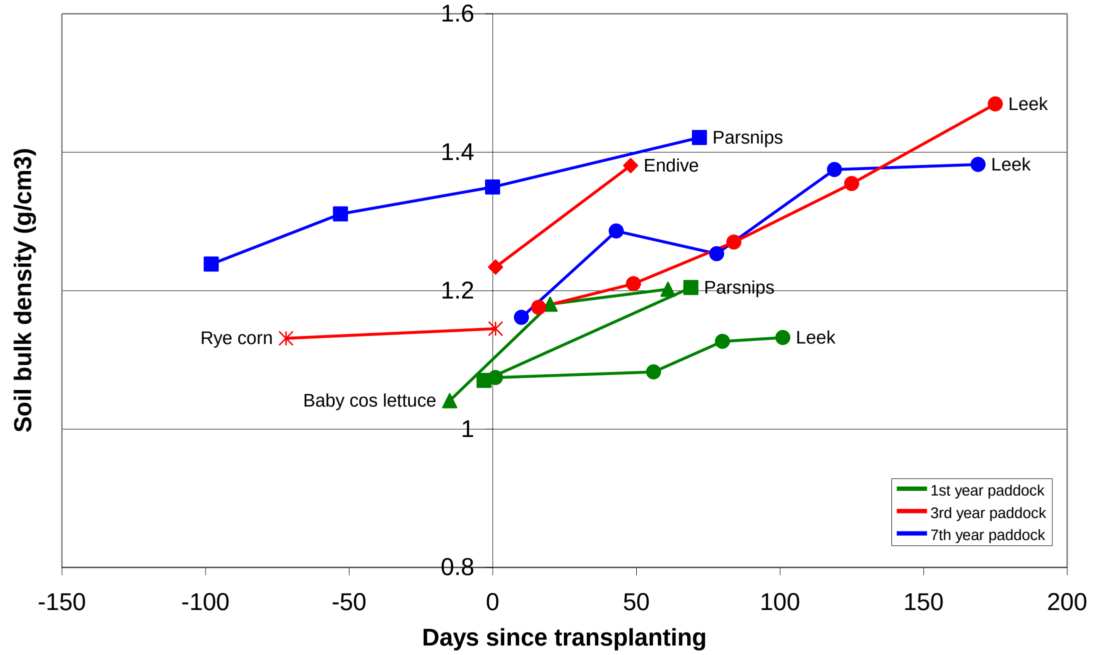


Figure 8.19 Soil bulk density (0-7 cm) at various times in parsnips (1st and 7th year paddock), baby cos-lettuce (1st year paddock), endive (3rd year paddock) and rye green manure (3rd year paddock). Negative values on the x-axis represent occasions when a paddock had been cultivated in preparation for the next crop, but the next crop had not yet been planted.

8.4 Conclusions

This study has illustrated, although not statistically proven, that important changes occur to soil properties when a loamy sand is changed from permanent pasture to a vegetable cropping system. Some of these soil changes are good for vegetable farming, such as a drop in salinity and an increase in phosphorous. Other soil properties have declined, but after seven years of vegetable cropping are still within acceptable levels, such as the available potassium and sulphur levels. Some of the changes are likely to be disadvantageous to vegetable cropping, particularly the decrease in organic and nitrate nitrogen. The decrease in nitrogen is closely associated with the decrease in total organic carbon, which had a pattern of decreasing from greater than 2.5% over the 0-30 cm depth range in the ‘0 year paddock’ to 1.0% in the ‘7th year paddock’. It is expected that this decline in SOM will have other implications to vegetable production than just nitrogen supply, although further research is required to quantify these effects. The farmer in this study already has excellent management practices to try to maintain soil organic matter, including returning crop residues, applying chicken manure, and growing green manures. It can be expected that for growers not undertaking these practices that any deleterious effects would be exacerbated. The use of chicken manure has been found elsewhere in this report to be economically viable for its nutrient benefit on a similar farm. Further monitoring over a longer time period is required to understand the full soil health benefits of maintaining higher SOM on these soil types. The high level of tillage used is likely to contribute greatly to the decline in SOM, and to production costs and greenhouse gas emissions. Therefore more research on the possibilities of reduced tillage systems for the vegetable industry would be desirable. Findings from this study and earlier trials in this report suggest that further research into organic amendments rates, timing and application method is required to better compliment fertiliser use and maximise long-term soil health.

9 Res-Calc

"Res-Calc": *an extension tool for calculating the quantity of organic carbon being returned to the soil.*

Organic carbon (OC) enters the soil in the form of organic matter (OM) in crop residues, root residues, animal manures, green manures, composts or other organic additives. This OC provides the energy and nutrients that drive the growth and activity of the soil microbial biomass. The soil microbial biomass helps build and stabilise soil structure, release and facilitate uptake of plant nutrients and suppress disease.

The amount of OC being returned to the soil, as well as the level of tillage, are the most important factors growers can control to influence soil OC levels and ultimately soil health. However, it is hard for growers to estimate the amount of OC returning to the soil from different rotations, manures and composts. This means they have no way of evaluating the potential soil health benefits or disadvantages of any practice change.

For this reason a simple calculator "Res-Calc" has been developed for vegetable growers to compare OC returning to the soil, in terms of tonnes of carbon per hectare, from different rotations, amendments or management practices.

Crop number	Crop grown	Crop use	Residue management	Inputted yield (t/ha)	Time green-manure growth period (months)	Soil organic amendment added	Amendment application rate (t/ha)	Yield Used (t/ha)	Total organic matter input (t/ha)	Total carbon input (t/ha)
1	Baby cos lettuce	Fresh market	Returned			Compost	10	9.50	3.0	1.3
2	Broccoli	Fresh market	Returned					7.70	7.3	3.3
3	Cauliflower	Fresh market	Removed					19.50	1.6	0.7
4	Celery	Fresh market	Returned					49.00	1.6	0.7
5	Parsnips	Fresh market	Returned					19.90	2.0	0.9
6	Baby cos lettuce	Fresh market	Returned					9.50	0.3	0.1
7	Cereal	Green-manure	Incorporated							
8	Cauliflower	Fresh market	Returned					19.50	5.1	2.3
9	Celery	Fresh market	Returned					49.00	1.6	0.7
10	Parsnips	Fresh market	Returned					19.90	2.0	0.9
11	Baby cos lettuce	Fresh market	Returned			Chook manure	5	9.50	3.3	1.5
12	Broccoli	Fresh market	Returned					7.70	7.3	3.3
13	Cauliflower	Fresh market	Removed					19.50	1.6	0.7
14	Cereal	Green-manure	Incorporated							
15	Parsnips	Fresh market	Returned					19.90	2.0	0.9
16	Baby cos lettuce	Fresh market	Returned			Compost	10	9.50	3.0	1.3
17	Broccoli	Fresh market	Returned					7.70	7.3	3.3
18	Cauliflower	Fresh market	Removed					19.50	1.6	0.7
19	Celery	Fresh market	Returned					49.00	1.6	0.7
20	Parsnips	Fresh market	Returned					19.90	2.0	0.9

Figure 9.1 Res-Calc data entry screen for rotation, yield and management practice

Growers use Res-Calc by entering their crop rotation and management practice into a table screen (Figure 9.1). There are 17 vegetable crops currently available from a pull down menu, as well as a cereal green-manure, and the potential to add three user defined crops.

Growers can add their specific crop yields or can select predefined crop yields, which are currently based on Victorian 2008/09 Australian Bureau of Statistics data. Res-Calc combines the yield data with reported information on crop harvest index (the ratio of yield to shoot material), root to shoot ratio, and the carbon concentration in organic matter, for each crop, to calculate the amount of OC being returned to the soil.

The residue management option defines the proportion of surface crop residue that remains after harvest depending on whether the crop residue is returned, removed, or other user defined options. Currently two organic amendments are available, while additional user defined amendments can also be added.

The total amount OC being returned to the soil for a specific rotation, of up to 30 crops, can be viewed either in tabular or graphical form. Three different rotations can be stored and the Res-Calc graphical display will superimpose the three rotations on a single graph (Figure 9.2). This enables farmers and agronomist to easily compare the impact of management options on the rate of OC input into the soil without actually growing a crop, helping them to choose more effective crop rotations and practices.

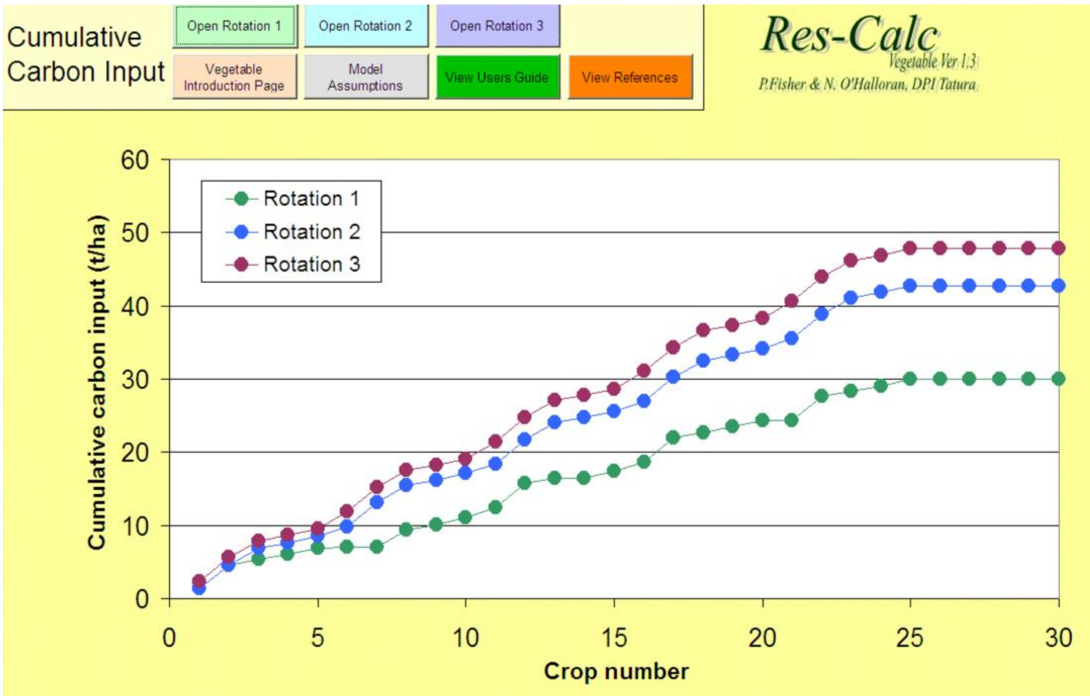


Figure 9.2 Res-Calc screen showing the cumulative OC input to the soil for three different rotations.

Res-Calc does not predict soil OC content which depends on both the rate of OC being returned to the soil (which can be calculated by Res-Calc) and the rate this OC decomposes in the soil. The rate of OC decomposition is dependent on the soil type, climatic conditions, and amount of tillage. A rotation that consistently returns more OC to the soil than an alternative rotation at the same location, will, however, over time result in higher soil OC and better soil health. In this way Res-Calc can be used to provide a simple tool for vegetable growers to assess the benefits or disadvantages of different crop management practices.

To obtain an estimation of how quickly and by how much soil OC content will change, it is necessary to use a carbon model. These models require data on the soil type and variation in climatic conditions, but also information on the amount of OC entering the soil. Therefore Res-Calc can be used both as a simple standalone tool to compare management options and also to provide the data necessary for more complex carbon modelling.

Res-Calc has been presented to vegetable growers and consultants at a number of forums and vegetable expos. Growers have generally been excited by the insight that Res-Calc provides, with many amazed to see the impact rotation can have on organic matter inputs. Res-Calc has also been demonstrated on a one to one basis with leading Victorian vegetable growers who were particularly interested in the use of Res-Calc for comparing the benefits of alternative green manure crops and using Res-Calc retrospectively to compare with their actual soil OC levels to see if this helps to explain how management has affected soil carbon levels.

Res-Calc (formally C-Calc) was originally developed with GRDC funding for broad acre farming, and with contributions from HAL and AusVeg a version has been produced to cover vegetable crops and practices. Res-Calc is intended to be down loadable from the web, and be incorporated into grower crop rotation recording software, but at the present time is available for evaluation from the authors Dr Peter Fisher (peter.fisher@dpi.vic.gov.au) and Nick O'Halloran (nick.ohalloran@dpi.vic.gov.au).

10 Communication/Extension activities

Communication of research outcomes to vegetable growers from the current temperate vegetable soil health project, the sub-tropical vegetable soil health project (VG06100), and overseas programs (i.e. the Cornell University Vegetable Soil Health Program) formed a major component of this project. On average, this project delivered more than one oral presentation per month to Australian vegetable growers for the life of the project. In addition, it produced a range of printed extension materials (four grower articles and seven guides and info-leaflets) that were distributed to vegetable growers at oral presentations and workshops, and on the internet (e.g. http://www.vgavic.org.au/pdf/VG07008_Soil_Health_brochure.pdf). Scientific outcomes from this project were communicated to colleagues through two peer reviewed articles, 16 scientific conference articles and one University thesis. It is anticipated that further scientific journal articles will be prepared from research in this project.

Communication activities in this project have increased the awareness of growers to soil health, and its potential for improving farm profits, yields, disease suppression, and input efficiencies for nutrients and water. A key measure of this has been growers' high attendance rates and desire for workshop presentations on soil health - most of which were initiated by industry. Preliminary outcomes from the communication activities have been:

- increased use of biofumigant rotations and amendments by vegetable growers – this practice is estimated to have increased by 10% in certain regions of Victoria since the start of the project.
- expressions of interest from private industry and Universities to further develop the soil health indicators identified in this and other projects (e.g. VG06100) into commercial tests available to growers. Development of such a program would provide growers with a mechanism for assessing and improving soil health on-farm.

Soil health provides exciting prospects for growers to better manage cropping inputs for greater profits. However, further research is required to develop robust systems that provide more predictable outcomes from improved soil health on-farm. Communication activities in this project have stimulated grower interest and awareness so that further developments in soil health science are likely to be rapidly heard and adopted by industry.

10.1 Workshops/Presentations

- Cranbourne Grower Workshop, August 28th, 2007
- Victorian Grower Workshop, May 28th, 2008
- National Soil Health Workshop, May 29th 2008
- South Australian Soil Health Workshop, May 30th, 2008
- Tasmanian Soil Health Workshop, June 2nd, 2008
- Field Tour, Bowen Growers Queensland, June 2nd - 4th, 2008

- Presentations to the 3rd International Biofumigation conference in Canberra ACT in July 2008 includi8ng the opening keynote address.
- Presentation to the Environmental Working Group of HAL and AusVeg representatives, 28th January, 2009
- Presentations to Australasian Soilborne Diseases Symposium in Thredbo NSW, in February 2009.
- AusVeg Conference, May, 2009 - Presentation on Soil Health by Ian Porter
- Werribee Field Days May 2009 - Presentation and display of the soil health project by Christina Hall and Robyn Brett, and practical demonstration of the carbon calculator by Nick O'Halloran
- 'Assessment and importance of soil health' Leeton, August 2009 - hosted by MIA Rural Services (David Sides)
- 'Assessment and importance of soil health' Griffiths, August 2009 - hosted by MIA Rural Services (David Sides)
- DPI Workshop at Amstel, Cranbourne - Ian Porter
- 'Soil health in the temperate Australian Vegetable Industry' AusVeg Conference at the Cranbourne Racecourse - Ian Porter
- National Compost Association Conference in Adelaide (Oct '09), Dr Peter Fisher was invited to speak on the soil health benefits of increasing soil carbon.
- 'Managing for Healthy Productive Soils' Grower Workshop (Nov '09), coordinated by Ausveg, with presentations by Ian Porter and Nick O'Halloran
- CropPlus Soil Carbon grower workshop (March '10) – presentation by Dr Peter Fisher
- 'Soil Health in the National Vegetable Industry'. National Vegetable Industry Conference, Broadbeach May 29th, 2010.
- 'Soil Health in the National Vegetable Industry'. Enviroveg workshop Virginia, 23 July, 2010.
- 'Soil biology workshop', Harcourt, Vic, 30 July 2010.
- 'Benefits of National IPM and Soil Health Programs' Devonport, August 4th, 2010
- 'Benefits of National IPM and Soil Health Programs' Gympie, August 11th, 2010
- 'Benefits of National IPM and Soil Health Programs' Gatton, August 12th, 2010.
- Carbon and Sustainability - A demonstration of how they relate and how they can be managed within the Australian Vegetable Industry. DAFF Climate Change Workshop. Sydney, August 19th
- 'Soil Health in the National Vegetable Industry'. Enviroveg workshop Cranbourne 22 October, 2010.
- 'Soil Health in the National Vegetable Industry'. Enviroveg workshop Werribee 29 October, 2010.
- 'Soil Health in the National Vegetable Industry'. Enviroveg workshop Longford 19th November, 2010.

Also 9 Soil health workshops for the Viticulture Industry were held at Wangaratta, Griffith, Bunbury, Swan Valley, Barossa, Cowra, South Gippsland and Renmark, Yarra Valley during the period October 2009 to December 2010 showing an overview of the vegetable R and D and benefits of investment into soil health on farm.

10.2 Grower Articles

- HSSF News; April 2008
- Vegetables Australia Article, July 2008, described the benefits to Australian vegetable soil health from the recent visit by Cornell University scientists (see below)
- 'Finding the balance' Vegetables Australia 5.5 March/April 2010
- 'Benchmarking soil health for improved crop health and yields' Vegenotes, Issue 18, 2010

10.3 Guides and Info-leaflets

- Soil Health Management Guide, DPI Victoria, March 2010
- Improving Soil Health, DPI, Victoria, May 2010
- Info leaflets (2010) Victorian Department of Primary Industries on:
  1. Soil Biota and SOM,
  2. Modelling SOM,
  3. Non-living SOM Fractions,
  4. SOM and the Carbon Cycle
  5. SOM and Nutrient Cycling

10.4 Refereed Scientific Publications

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

Porter, I.J. et al. (2011). Influence of soil organic matter on soil health, crop productivity and N_2O emissions in vegetable crops. *Acta Hort.* (in submission)

10.5 Conference Papers

Brett, R.W. et al. (2008). Validation of biological indicators to benchmark soil health in the vegetable industry of temperate Australia. Australasian Soilborne Diseases Symposium, 5-7 February 2009.

Brett, R. Gounder, R., Mattner, S., Hall, C. And Porter, I. (2009). Evaluation of soil health indicators in the vegetable industry of temperate Australia. Australian Plant Pathology Conference, Newcastle, 29 Sept-1 Oct 2009

Gounder, R.K. et al. (2008). Evaluating biofumigant amendments for soil health management in the temperate Australian vegetable industry. Third International Biofumigation Workshop, 21-24 July, 2008, Canberra, Australia

Guijarro, M.B. et al. (2010). Suppression of damping off of radish caused by Rhizoctonia solani AG 2.1 with soil carbon amendments. Australasian Soilborne Diseases Symposium, 9-11 August 2010.

Guijarro, M.B. et al. (2011). Suppression of damping off of radish with soil carbon amendments. Australian Plant Pathology Conference (accepted paper).

Porter, I.J. et al (2009). Benchmarking common farm practices for their effect on soilborne diseases, soil health, crop productivity and profit in vegetable crops. Australasian Soilborne Diseases Symposium, 5-7 February 2009.

Porter, I.J. et al. (2010). Influence of soil organic matter on soil health, soil carbon, and disease suppression in vegetable crops. Australasian Soilborne Diseases Symposium, 9-11 August 2010.

Porter I., Brett R., Mattner S., Hall C., Gounder, R., O'Halloran , N., Fisher P. and Edwards J. 2009. Can investment in building up soil organic carbon lead to disease suppression in vegetable crops? Australian Plant Pathology Conference, Newcastle, 29 Sept-1 Oct 2009

Porter, I and Edwards J (2009). Assessing and Improving Soil Health. Australian Society for Aenology and Viticulture Conference, Mildura, 2009

Porter, I.J., Mattner, S.W., Edwards, J. 2010. Importance of soil organic matter to soil health and disease suppression in vegetable crops. Australasian Soilborne Diseases Symposium, 9-11 August 2010.

Porter, I.J. Mattner, S., Lazarovits, G. (2008). The benefits, costs and challenges of biofumigation to control soilborne pests and diseases. Third International Biofumigation Workshop, 21-24 July, 2008, Canberra, Australia

O'Halloran, N. et al. (2011) Organic amendments necessitate a trade-off between building soil organic carbon and supplying crop nitrogen. International Symposium Organic Matter Management & Compost Use in Horticulture (accepted paper)

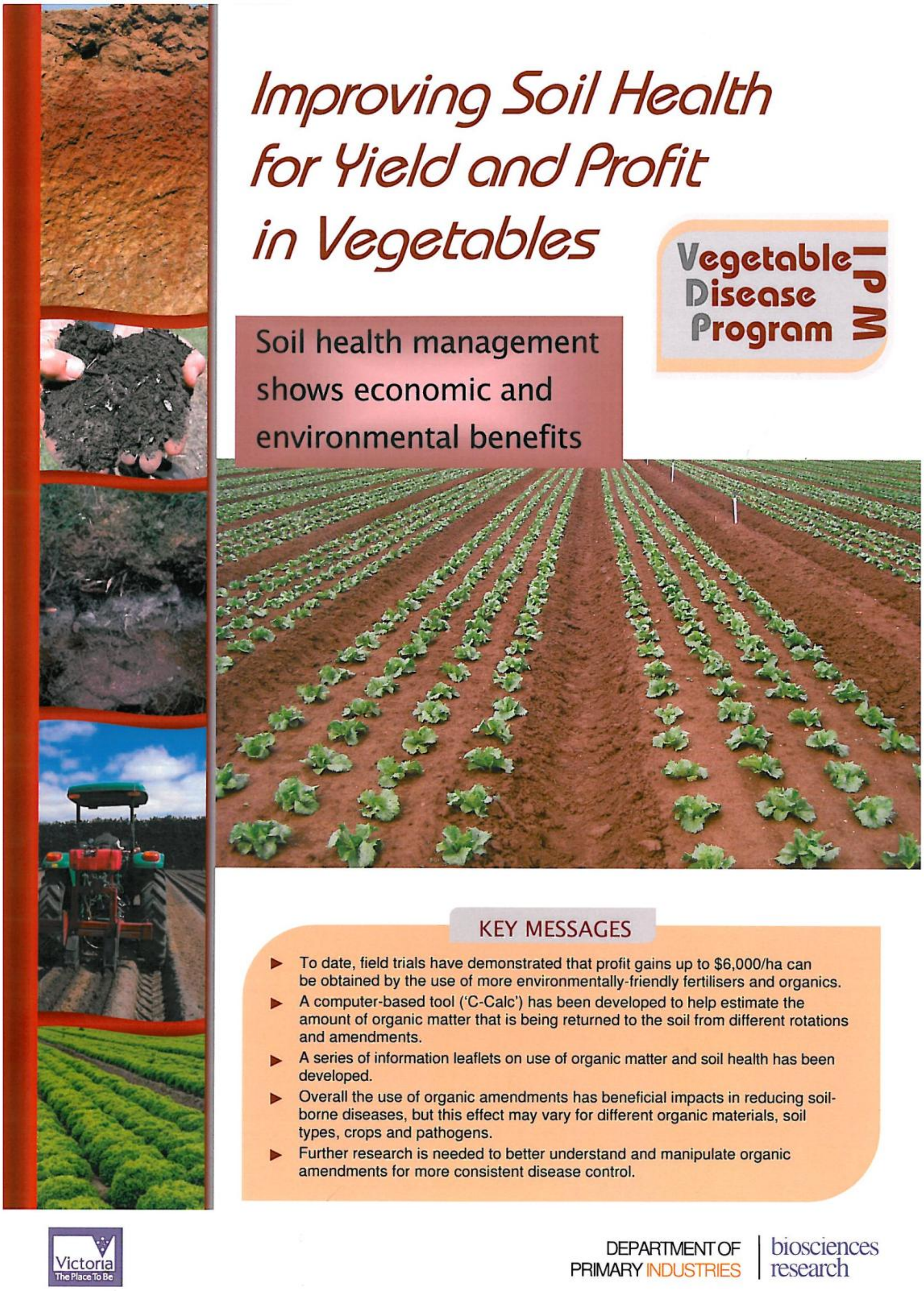
O'Halloran, N. Fisher, P. Aumman, C. and Rab, A. (2010). Relationship between organic matter retention and soil carbon in irrigated farming systems. 19th World Congress of Soil Science, Brisbane, 2010.

Weda, G, Schruers, D, Ingram, M., and Porter, I. (2008). Experiences of Victorian horticultural growers with biofumigation. Third International Biofumigation Workshop, 21-24 July, 2008, Canberra, Australia

10.6 Thesis

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

Appendix 10.1 Soil health management guide



Improving Soil Health for Yield and Profit in Vegetables

Vegetable Disease Program IPM

Soil health management shows economic and environmental benefits

KEY MESSAGES

- To date, field trials have demonstrated that profit gains up to $6,000/ha can be obtained by the use of more environmentally-friendly fertilisers and organics.
- A computer-based tool ('C-Calc') has been developed to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.
- A series of information leaflets on use of organic matter and soil health has been developed.
- Overall the use of organic amendments has beneficial impacts in reducing soil-borne diseases, but this effect may vary for different organic materials, soil types, crops and pathogens.
- Further research is needed to better understand and manipulate organic amendments for more consistent disease control.

Victoria The Place To Be

DEPARTMENT OF PRIMARY INDUSTRIES | biosciences research

Researchers at the Victorian Department of Primary Industries are finding that a range of different soil health practices have both environmental and economic benefits to growers. By measuring biological, physical and chemical properties in soil they are identifying which methods improve soil quality, whilst providing good yields and maximum profit.

Measuring & Monitoring Soil Health

Good soil health is largely driven by the amount of carbon in the soil, which provides food for soil organisms (good and bad) and helps build the good soil structure required for root growth and water storage. Agricultural practices tend to reduce soil carbon levels, and the greater the intensity of cultivation, the greater the loss in soil carbon.

Figure 1 illustrates the decline in carbon levels measured at a grower's property following 0, 1, 3, and 7 years of vegetable production after pasture.

A range of tests can be used to estimate whether your soil has a soil health problem, and whether it is principally a soil physical, chemical or biological issue (Table 1). A benchmarking trial using these tests compared more than 50 sites in the temperate vegetable industry and showed that many growers were overusing fertilisers. Seventy percent of sites recorded high or excessive levels of phosphorus and 90% of sites recorded excessive levels of potassium.

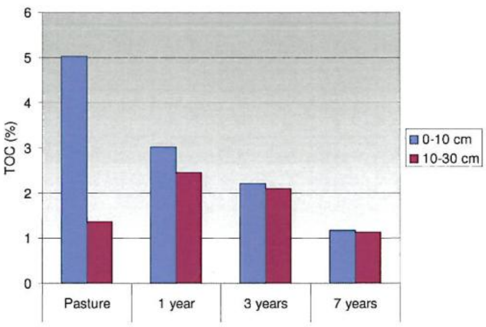


Figure 1. Reduction in total organic carbon (TOC) levels after increasing years of vegetable cropping (Sandy soil, Cranbourne, Vic.).

Table 1. Examples of some physical, chemical and biological tests of soil health.

Soil Physical Tests	
Penetrometer resistance	Identifies potential compaction issues that lead to poor root growth and water infiltration.
Water infiltration	Poor water infiltration can lead to poor root growth and poor water uptake by the plant.
Soil Chemical Tests	
Nutrient analyses	Ensure measured nutrients fall within an acceptable range for your crop as oversupply can leach nutrients into water ways.
Labile carbon	A good measure for carbon as it is the fraction of soil organic matter readily available as food for soil microbes. Particularly useful for monitoring management practices that build up soil organic matter.
Soil Biological Tests	
Biological activity (FDA hydrolysis and CO_2 respiration)	Measuring total soil microbial biomass can identify soils that contain high levels of microbes that can recycle nutrients from organic sources, 'glue' soil aggregates together, and may reduce some disease problems by out-competing soil-borne pathogens.
Nematode community structure	Provides an indication of the impact of management on soil microbial diversity and disturbance within soil systems.

Economic Benefits of Soil Health

In a 3-year field trial a wide range of soil amendments with different soil health impacts were tested. Encouragingly, most of them resulted in a positive financial return for growers. Particularly, slow release ammonium fertilisers such as Alzon® increased broccoli yields by 15% above standard grower practice, translating to increased profits of up to $6,000/ha, depending on the year and season (Figure 2). Organic amendments also had positive effects, but due to the slower breakdown of these products, positive profits occur more slowly.

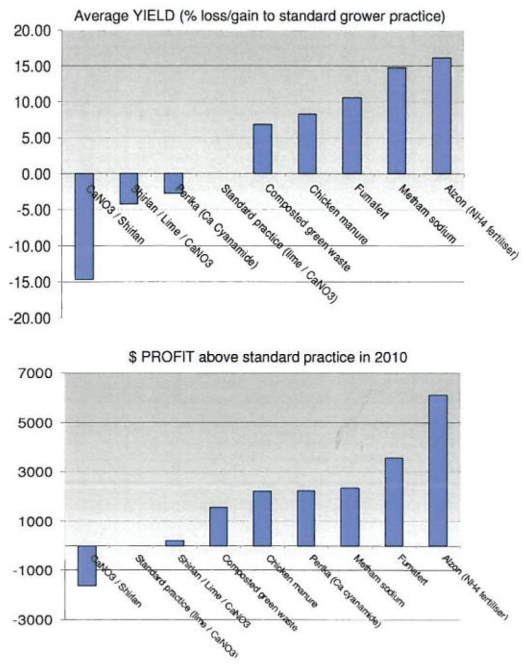


Figure 2. Average % yield of broccoli over 3 seasons from 2008-2010.and $ profit in 2010 gained or lost compared with the standard grower practice from different treatments in a sandy loam in Boneo, Victoria.

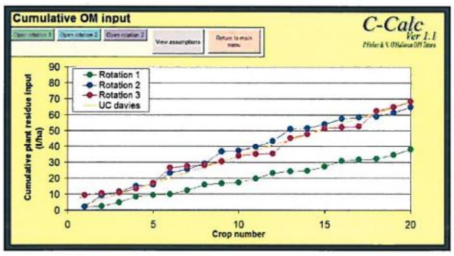
Effect of Soil Carbon on Disease

The interaction of organic amendments with soil-borne diseases is multifaceted. Organic matter can decrease soil-borne pathogens, either by chemical processes (e.g. production of toxins) or by biological processes (e.g. through changes in soil microflora that make soils more disease suppressive). At the same time organic matter, particularly undecomposed residues, can increase disease by acting as a food source for certain pathogens. For example, amending field soils with silage reduced the severity of clubroot of broccoli in trials, but amendments with chicken manure, compost and lignite increased it. In pot trials, amending infested soils with lignite, compost and humate tended to decrease damping off of radish (caused by *Rhizoctonia solani*), but biochar increased it. These differences in control were related to the C:N ratio of the organics, the breakdown rate and products of the material, and the effect of the amendment on soil pH. More research is needed to better understand and manipulate organic amendments for consistent disease control. This may include the use of different forms of organic matter, integrated with nutrient inputs or more strategic fumigant and fungicide use.

'C-Calc' -

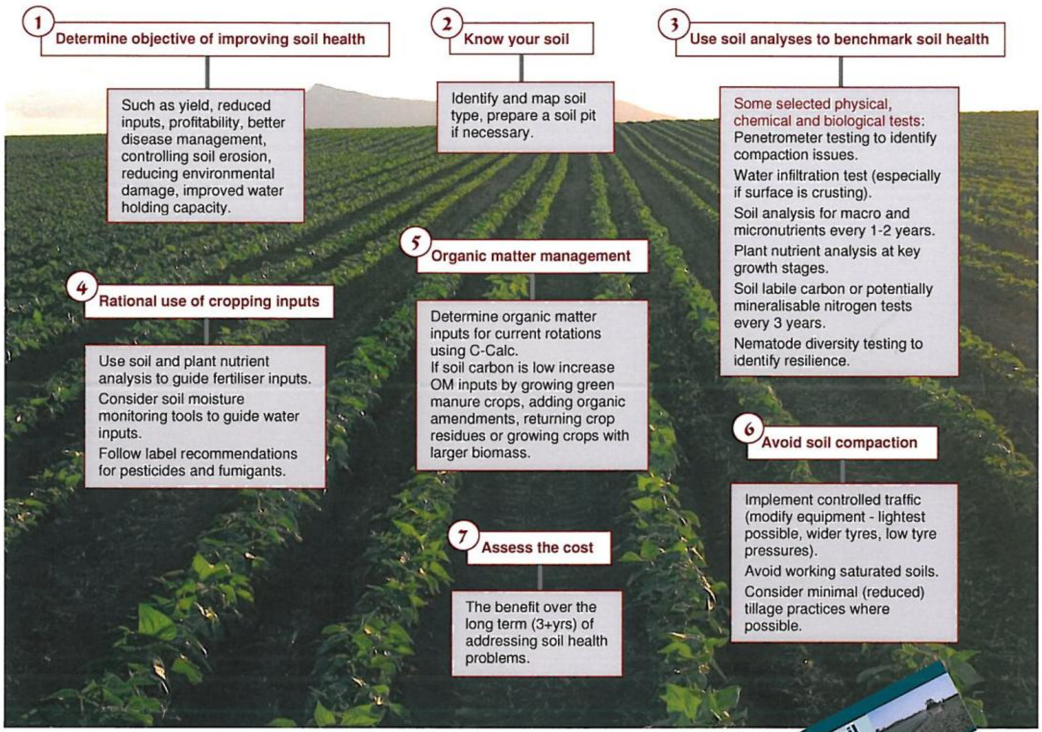
A Tool to assist Calculation of Organic Matter added to Soil

The amount of organic matter (OM) being returned to the soil is an important factor which influences soil carbon levels and soil health. DPI has developed a computer tool called 'C-Calc' that estimates the carbon contribution added to soil from rotations or organic amendments. C-Calc allows growers to compare different practices without actually growing a crop, helping to choose more effective crop rotations and practices.



Soil Health Management Guide

A series of steps to start improving soil health is shown below.



Further Information

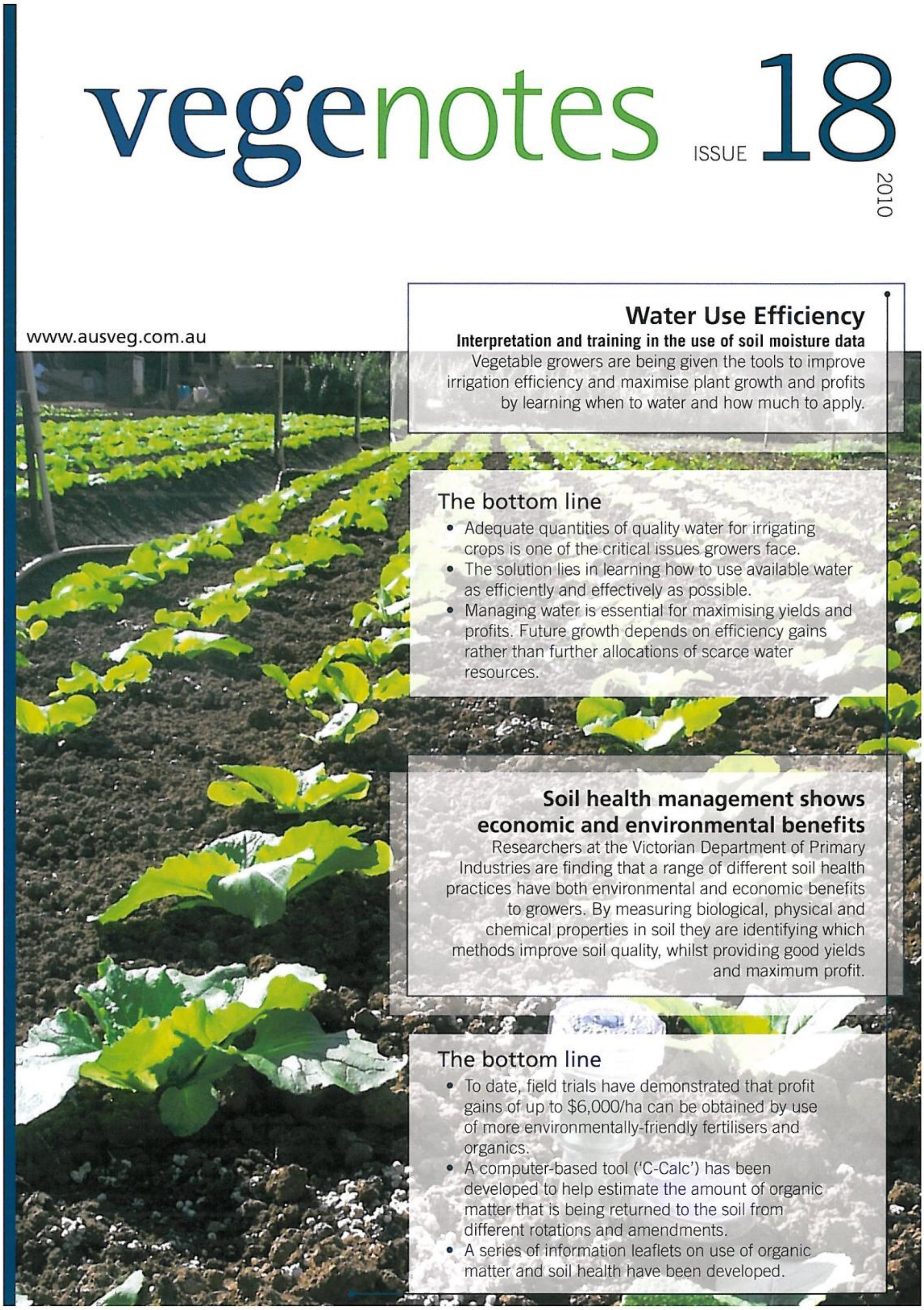
General information on soil health is available from:

- DPI Vic: www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-home
- Soil Health Ute Guide http://www.ausveg.com.au/healthy-soils.cfm
- Soil Quality: www.soilquality.org.au/
- Soil Health Knowledge Bank: www.soilhealthknowledge.com.au

A series of "Soil Organic Matter Info-Leaflets" have been developed by DPI Victoria to bridge the gap between general information and the scientific literature. They are available by contacting peter.fisher@dpi.vic.gov.au or nick.ohalloran@dpi.vic.gov.au

The VicDPI Vegetable Soil Health Team includes: Ian Porter, Scott Mattner, Jacky Edwards, Robyn Brett, and Belen Guijarro (Knoxfield, 03 9210 9222), and Nick O'Halloran and Peter Fisher (Tatura, 03 5833 5222).

Appendix 10.2 Vegenotes Issue 18 (2010)



vegenotes ISSUE 18

2010

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Water Use Efficiency

Interpretation and training in the use of soil moisture data

Vegetable growers are being given the tools to improve irrigation efficiency and maximise plant growth and profits by learning when to water and how much to apply.

The bottom line

- Adequate quantities of quality water for irrigating crops is one of the critical issues growers face.
- The solution lies in learning how to use available water as efficiently and effectively as possible.
- Managing water is essential for maximising yields and profits. Future growth depends on efficiency gains rather than further allocations of scarce water resources.

Soil health management shows economic and environmental benefits

Researchers at the Victorian Department of Primary Industries are finding that a range of different soil health practices have both environmental and economic benefits to growers. By measuring biological, physical and chemical properties in soil they are identifying which methods improve soil quality, whilst providing good yields and maximum profit.

The bottom line

- To date, field trials have demonstrated that profit gains of up to $6,000/ha can be obtained by use of more environmentally-friendly fertilisers and organics.
- A computer-based tool ('C-Calc') has been developed to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.
- A series of information leaflets on use of organic matter and soil health have been developed.

Water Use Efficiency

Introduction

The use of water in vegetable production is both highly efficient and profitable when compared to other agricultural sectors, with the vegetable industry accounting for as little as 4.6 per cent of the total water used *(ABS Water Use on Farm 2003-04)*. Sub-surface drip irrigation, computer-controlled overhead sprinklers and soil moisture monitoring equipment are helping growers to supply water only when and where it is required, however drought and increased demand for water across many growing regions has highlighted the need for even greater efficiency.

Applied Horticultural Research (AHR) has developed a training guide and series of regional-specific workshops outlining the principles of effective water management. The information is helping growers to manage crop water use for maximum returns while minimising production risks.

Water-wise

The main objective of this project is to try to reduce the amount of water used to grow vegetable crops through greater on-farm water use efficiency. This can be achieved by:

- Improving information to support irrigation choices and water management by developing real water use efficiency and water movement data in common vegetable crops from major growing regions.
- Providing training on how to use soil moisture data to efficiently schedule irrigations and maximise yield and quality based on crop water requirements and water movement in local soil types.

Data collected from previous AHR field trials and soil moisture monitoring equipment has been analysed in order to provide case studies and help demonstrate the impact and importance of effective water management. This information is in the booklet managing *Water for Yield and Profit.*

Water efficiency means applying enough water to meet the needs of the plant. No more or no less.

The publication also examines:

1. Why plants need water – impact of under or over-watering on plant physiology, crop quality and yield.
2. Water and soil – understanding the readily available water content of different soils.
3. Determining the timing and amount of irrigation – calculating a water use budget using crop coefficients and crop factors.
   Matching crop water use with the readily available water content of the soil in order to schedule irrigation events.
4. Understanding how to use the output from soil moisture sensors – examples of real data from AHR field trials using soil moisture probes.
5. A reference and resource list of other materials that cover water use efficiency training and soil moisture monitoring.

A series of workshops have been held around Australia in conjunction with the release of the booklet. Each provided a summary of the key principles and additional information available, along with a series of practical steps to help growers work through the calculations required to determine their irrigation needs. The courses not only improved the level of knowledge within the industry, but encouraged growers to evaluate their business and make positive changes.

Ways to improve water use efficiency

1. Calculate a water budget for specific crops to establish exactly how much water is required.
2. Dig soil pits in order to confirm soil characteristics and the variability of soil types across a paddock and calculate and understand the Readily Available Water (RAW) content.
3. Check the wetting pattern of the soil after irrigation to ensure that the entire root zone is wet.
4. Investigate the options for using soil moisture monitoring to manage irrigation scheduling.

The project was highly effective in terms of promoting, organising and presenting training material. Additional workshops are possible if there is sufficient industry demand.

Further Reading

The publication *Managing Water for Yield and Profit* can be obtained in hardcopy or CD format from AHR Training by telephoning 02 9527 0826. It can also be downloaded at www.ahr.com.au.

AHR Pty Ltd contributed voluntary funds to this project, VG06136 with further funding provided by HAL using the National Vegetable Levy and matched funds from the Australian Government.

Statistics supplied by AHR Training

Good news

- The vegetable industry is roughly twice as efficient in its use of water as it was a decade ago.
- The value return from vegetable production increased from $1,762/ML used in 1996/97 to $3,207/ML in 2000/01 (ABS 2001).
- The industry average water use is 4.1 ML per hectare,

compared to the national average for agriculture, which is 4.3 ML per hectare.

- The industry uses 4.6 per cent of the total water used by irrigation (ABS Water Use on Farm 2003-04).

These statistics show the vegetable industry is an efficient user of water compared to other sectors, but there are more improvements to be made.

Bad news

- Between 1983/84 and 1996/97, irrigation water use in Australia increased by 75 per cent.
- In Australia, irrigated agriculture uses 65 per cent of consumed water.
- The Australian water resource assessment for 2000 estimated that 26 per cent of Australia's river basins and 34 per cent of Australia's groundwater were exceeding sustainable extraction limits.

Water Use Efficiency

Water use efficiency is a generic term that covers a range of performance indicators irrigators can use to monitor the performance of their irrigation practices.

Irrigation water use index (IWUI) =

$$\frac{\text{Total production for farm (Tonnes)}}{\text{Irrigation water applied to farm (ML)}}$$

Operating profit water use index (OPWUI) =

$$\frac{\text{Gross return (\$) - Variable costs (\$) - Overhead Costs (\$)}}{\text{Total water used on farm (ML)}}$$

Benchmarking soil health for improved crop health and yields

Measuring & Monitoring Soil Health

Good soil health is largely driven by the amount of carbon in the soil which provides the food for soil organisms (good and bad) and helps build the good soil structure required for root growth and water storage. Agricultural practices tend to reduce soil carbon levels. The greater the intensity of cultivation, the greater the loss in soil carbon will tend to be. A range of tests (e.g. penetrometer resistance, nutrient and biomass measurements) can be used to estimate whether your soil has a health problem, and whether it is principally soil physical, chemical or biological issue. A benchmarking trial using these tests showed many growers were overusing fertilisers, with 70% of sites recording high or excessive levels of phosphorus and 90% of sites recording excessive levels of potassium.

The value and feasibility of a National benchmarking program for soil health in the Australian vegetable industry, is currently being assessed.

Field trials in Southern Victoria

Examples of some physical, chemical and biological indicators of soil health:

Soil Physical Tests	
Penetrometer resistance	Identifies potential compaction issues leading to poor root growth and water infiltration.
Water infiltration	Poor water infiltration can lead to poor root growth and poor water uptake by the plant.
Soil Chemical Tests	
Nutrient analyses	Make sure measured nutrients fall within an acceptable range for your crop as oversupply can leach nutrients into waterways.
Labile carbon	A good measure for carbon as it is the fraction of soil organic matter readily available as food for soil microbes. Particularly useful for monitoring management practices that build up soil organic matter.
Soil Biological Tests	
Biological activity (FDA hydrolysis and CO2 respiration)	Measuring total soil microbial biomass can identify soils containing high levels of microbes that can recycle nutrients from organic sources, 'glue' soil aggregates together, and may reduce some disease problems by out-competing soil-borne pathogens.
Nematode community structure	Provides an indication of the impact of management on soil microbial diversity and disturbance within soil systems.

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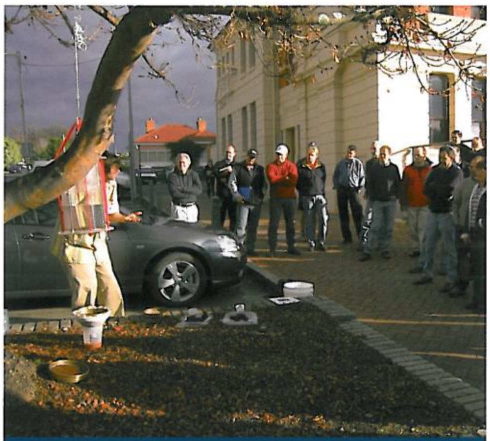
Economic Benefits of Soil Health

A wide range of soil amendments with different soil health impacts were tested in a three year field trial. Most resulted in a positive financial impact for growers. Tests using slow release ammonium fertilisers gave average yields of broccoli 16% greater than the standard yield. These are considered beneficial to reducing nitrogen runoff. This translated to increased profits of up to $6,000/ha depending on the year and season. Adding organic amendments also had positive impacts, but due to the slower breakdown of these products, profits occur more slowly.

'C-Calc' - A tool to assist calculation of amount of organic matter added to soil

The amount of organic matter (OM) being returned to the soil is an important factor influencing soil carbon levels and soil health. This project has developed a computer tool called 'C-Calc' estimating the carbon contribution added to soil from rotations or amendments. It allows growers to compare different practices without actually growing a crop.



Soil health workshop in Devonport, Tasmania

Soil Health Management Guide

A series of steps to improve soil health are shown below.

1. Determine objective of improving soil health (eg yield, reduced inputs, profitability, poor emergence etc.).
2. Know your soil (identify and map soil type, prepare a soil pit if necessary).
3. Use soil analyses to benchmark soil health such as:
   - Penetrometer testing to identify compaction issues.
   - Water infiltration test (especially if surface is crusting).
   - Analysis for macro and micronutrients every 1-2 years.
   - Plant nutrient analysis at flowering.
   - Soil labile carbon or potentially mineralisable nitrogen tests every three years.
   - Nematode diversity testing to identify resilience.
4. Rational use of cropping inputs (refer to benchmark data for optimal plant growth):
   - Use nutrient analysis to guide fertiliser inputs.
   - Use soil moisture monitoring tools to guide water inputs.
   - Follow label recommendations for pesticides and fumigants.
5. Organic matter management:
   - Determine organic matter inputs for current rotations using C-Calc.
   - If soil carbon is low increase OM inputs by growing green manure crops, adding organic amendments, returning crop residues or growing crops with larger biomass.
6. Avoid soil compaction:
   - Implement controlled traffic (modify equipment e.g. low tyre pressures).
   - Avoid working saturated soils.
   - Consider minimal tillage practices where possible.
7. Assess the cost:
   - Benefit over the long term (3+yrs) of addressing soil health problem.

Further Information

General information on soil health is available from:

DPI Vic
www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-home
Soil Health Ute Guide
www.ausveg.com.au/healthy-soils.cfm
Soil Quality
www.soilquality.org.au/
Soil Health Knowledge Bank
www.soilhealthknowledge.com.au

Further information on this project, VG07008, can be found by contacting peter.fisher@dpi.vic.gov.au or nick.ohalloran@dpi.vic.gov.au. A series of "Soil Organic Matter Info-Leaflets" have been developed by DPI Victoria to bridge the gap between general information and the scientific literature. These can also be obtained through the above contacts.

DPI Victoria contributed voluntary funds to this project, VG06136 with further funding provided by HAL using the National Vegetable Levy and matched funds from the Australian Government.

Please contact Erin Lyall at AUSVEG on 03 9822 0388 or at erin.lyall@ausveg.com.au to submit topics for potential inclusion in future editions of Vegenotes.

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Appendix 10.3 Soil Heath Management Chart

Soil Health: 'Benchmarking soil health for improved crop health, quality and yields in the temperate Australian vegetable industries'.

Project: VG07008 funded by HAL, Vic DPI, AusVeg Levy

Better management of soil health can offer growers greater profits, sustained yields, reduced input costs of fertilizer and pesticides, disease suppression, increase efficiency of water use and improved environmental outcomes. Read on…!

Over the past 2 years, the Victorian Department of Primary Industries, with financial support from Horticulture Australia Limited and the AusVeg Levy, has investigated the effects of common soil management practices on soil health and crop productivity in the vegetable industry. Examining the physical, chemical and biological changes in soil after different treatments are applied has enabled them to identify cropping practices which improve soil health. In addition, the potential cost / benefit of several key organic and inorganic amendments used throughout the vegetable industry has been determined by measuring the response of crops after treatment.

Large long term trials on commercial vegetable farms in sandy soils have demonstrated the benefits of utilising sustainable cropping practices:

- Treatments which reduce environmental nutrient flow (eg. slow release ammonium fertilisers and targeted nutrient treatments) gave yields of broccoli and profitability at least 20% greater than the standard grower practice and equivalent to the use of fumigant chemicals. This translated to increased profits of $2,000 to $6,000/ha, depending on the year and season.

- Organic treatments such as chicken manure, composted green waste and silage increased yields by an average of 5 to 15% and increased organic carbon in soil by over 100%. However, profit margins were only just starting to increase over the long term in the 3rd season of treatments.

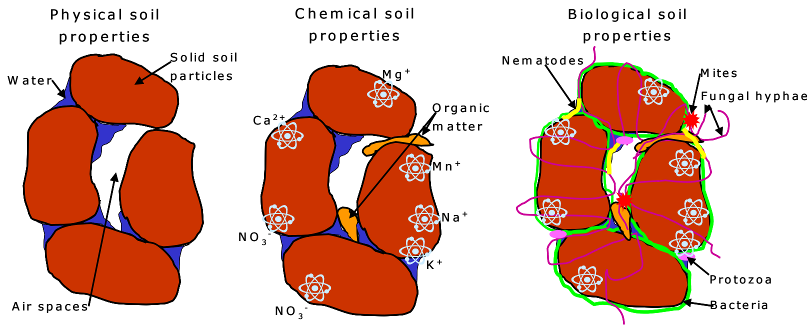
- Benchmarking studies indicated that between 70 to 90% of crops are over-fertilised. A subsequent trial conducted on a major commercial property showed that fertiliser input could be reduced by up to 50% without affecting yields.

- In some trials, water use could be reduced by 20% in soils treated with organic composts without affecting yields, although water availability was not affected.

1. How can an individual grower measure soil health?

There are three main properties of soil which influence soil health: physical, chemical and biological (Figure 1). This project (together with other research in Australia and overseas) aimed to define a set of indicators, or measures, which will show the effect of changed management practices on the health of cropped soils.

Fig. 1: Physical, chemical and biological properties of soil.



Source: Tony Pattison, QDPIF

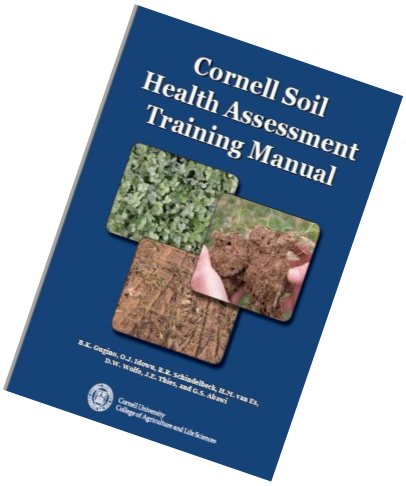
Soil health indicators are physical, chemical and biological tests that can be applied to soil. They may be tests that growers regularly carry out such as pH and nutrient analyses, or may be additional tests such as nematode community analysis. To determine which indicators are most relevant to temperate vegetable soils in Australia, more than 30 tests have been trialled on a range of farms. Sites were paired on the basis of fumigated/non-fumigated, application of fertiliser or organic amendments, etc., in order to identify the best tests.

Soil Physical Ttests	
Penetrometer resistance	A penetrometer is pushed into the soil with steady force and the resistance measured to identify potential compaction issues which lead to poor root growth and water infiltration.
Aggregate stability	Indicator of soil structure. A well-structured soil has stable aggregates that are not easily dispersed in water. Can be used to guide improvements in traffic management and tillage.
Water infiltration	Soil infiltration rate is strongly affected by management practices. A well-structured soil has enough pores to promote aeration and water infiltration, thus allowing for roots to easily penetrate through the soil.
Soil Chemical Tests	
Soil pH	pH is an indicator of acidity or alkalinity of soil. Nutrient form and availability are highly dependent on soil pH.
Nutrient analyses	Insufficient nutrients reduce plant growth and vigour, but an oversupply of nutrients can be toxic to plant growth and pollute waterways through leaching.
Labile carbon	An indicator of the fraction of soil organic matter readily available as food for soil microbes. Positively correlated with % organic matter and aggregate stability. Particularly useful to monitor practice changes for building up soil organic matter.
Cation exchange capacity (CEC)	The CEC describes the ability of the soil to retain nutrients in the vicinity of the root zone, ensuring they are available for plant use.
Soil Biological Tests	Soil organisms decompose plant residues, recycle nutrients, 'glue' soil aggregates together, and can reduce disease problems by out-competing soil-borne pathogens.
Biological activity (FDA hydrolysis and CO_2 respiration)	Used to measure total soil microbial biomass.
Fungi:bacteria ratio	Gives a general indication of soil health - higher ratios (25% cf 5%) indicate a more stable undisturbed system.
Nematode community structure	Nematodes (microscopic worms) provide a good indicator of the impact of management on microbial diversity as nematodes feed on bacteria, fungi and other nematodes. The relative proportion of each nematode group reflects different microbial community structure.

Table 1. Examples of some useful soil health indicator tests

The Ute Guide and International Soil Health Programs assist Australian Vegetable Growers

Soil health programs around the world, such as the Cornell University Soil Health Program, use similar indicator tests to develop programs that enable farmers to score their soil health and keep track of improvements that work for their farm. The Australian project is currently evaluating whether such a program would be feasible and of use to vegetable growers nationally (http://www.hort.cornell.edu/soilhealth/) in conjunction with the information already available (The Ute Guide: http://knowledge-exchange.ausveg.com.au).



Benchmarking Fertilizer Practices in Temperate Australia

Using indicators to benchmark the southern temperate vegetable growing areas revealed that fertiliser rates are often excessive. Only 20% of sites tested had optimum phosphorus levels for vegetable production, with almost 70% recording high or excessive levels (Fig. 2). Similarly, 90% of sites had excessive levels of potassium (Fig. 3).

Fig. 2: Phosphorus levels (Olsen P) at 49 sites on different vegetable farms

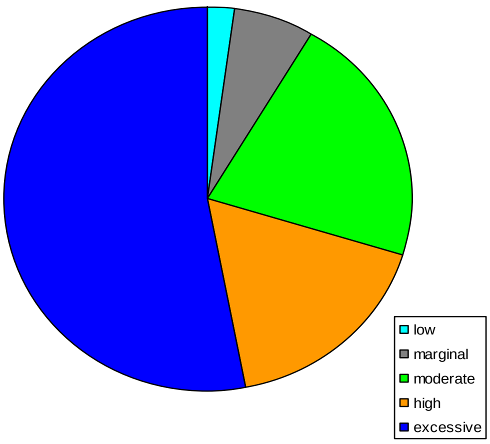
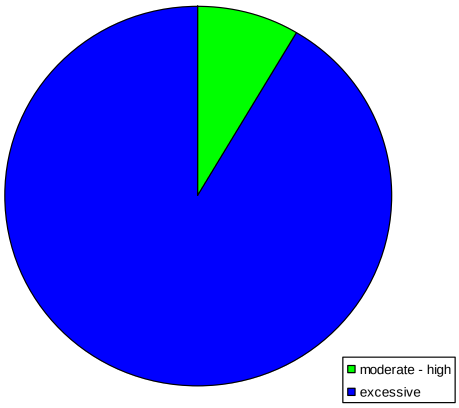


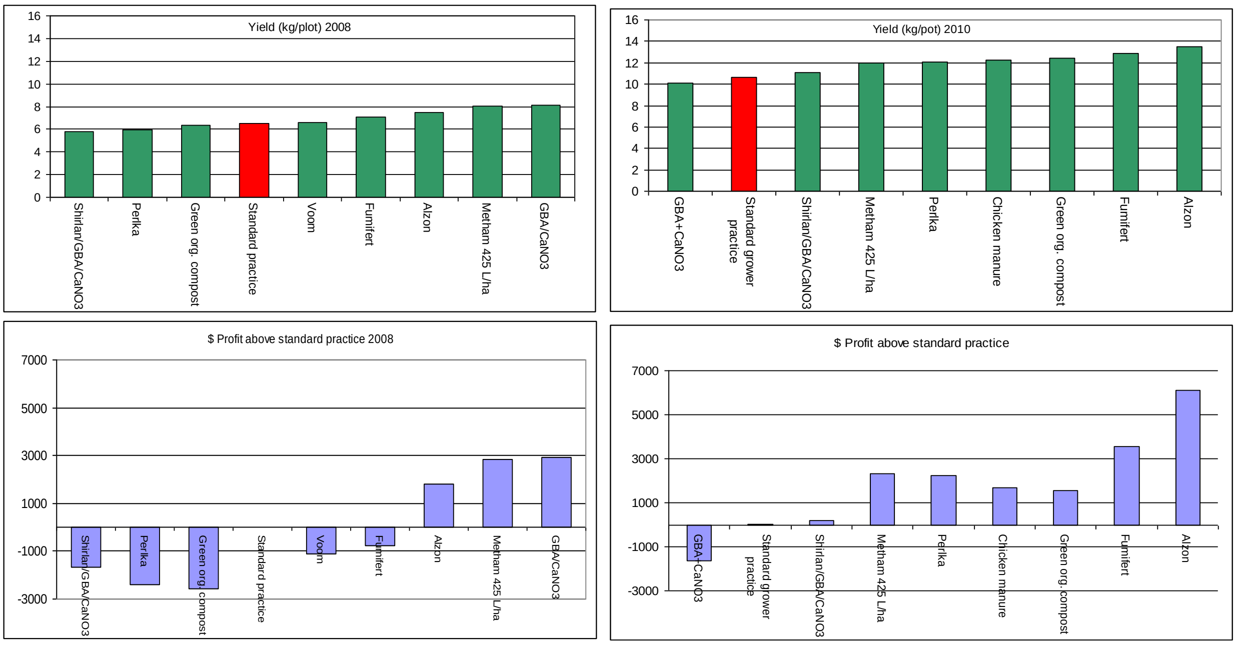
Fig. 3: Potassium levels at 49 sites on different vegetable farms



Soil Health Field trials (2008 to 2010)

Comparing broccoli yields and profit under different fertiliser, pesticide and organic inputs (Boneo, Victoria)

Treatments were:
- Composted chicken manure and green organic waste
- Biofumigants - Fumifert® and Voom® at rec. rates
- Clubroot treatments - Lime and $CaNO_3$ with or w/o Shirlan® fungicide
- Nitrogen forms that minimise nitrate flow - Alzon® and Perlka®
- Metham sodium fumigant
- Standard grower practice



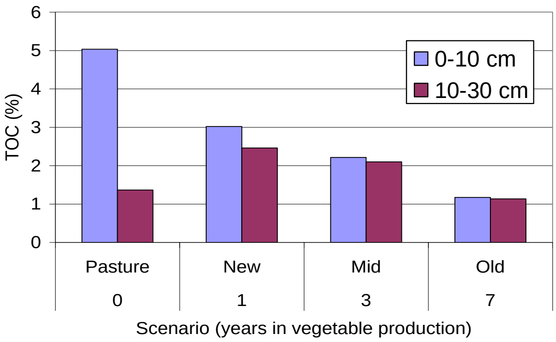
Autumn 2008 Summer 2010

Fig 4: Effect of various organic and inorganic amendments applied to soil on yield and profit in a loamy sand at Boneo in Victoria in 2008 and 2010 (Results in Autumn 2009 not shown but trends similar to 2009)

Key Results:
- Several treatments that promote soil health produced equivalent or higher yields than standard grower practice or fumigation. The yield response and profitability was greater in summer than autumn.
- 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.
- The composts (green organic waste, chicken manure) and biofumigants (eg. Fumafert) increased yields and profit in summer, but not in autumn.

Note: The trials had no significant soilborne diseases, and the benefits in crop productivity produced by the best treatments above were related to better soil health, soil quality, nutrient and water availability.

Cultivation burns off soil carbon



Vegetable growers cultivate their soil to incorporate crop residues, control weeds and prepare seed beds. However, this contributes to a decline in soil carbon levels, which exacerbates soil structural problems, which requires more cultivation! To break this destructive cycle, vegetable growers should consider adding organic amendments to the soil or rotating with crops high in organic matter or that require less cultivation (eg. fodder crops, pasture).

Fig. 5: Total organic carbon (%TOC) present in a sandy soil at 0, 1, 3, and 7 years after conversion from pasture to vegetable production on a commercial farm in Victoria.

Benefits of adding organic matter to soil

Organic amendments vary in the amount of carbon they contribute to soil and the yield response also varies accordingly. For instance, animal manures, green manures, silage and crop residues contain a large proportion of carbon that is 'labile', meaning it is more rapidly decomposed by soil organisms. In contrast, composts and lignite contain carbon in forms that are resistant to microbial decomposition. In a large long term field trial at a vegetable farm in Boneo, Vic., two applications of chook manure @ 19.6 and 4.9 t C/ha did not maintain soil carbon levels any higher than smaller applications of compost @ 13.6 and 5.0 t C/ha or lignite @ 5 t C/ha (Fig 6).

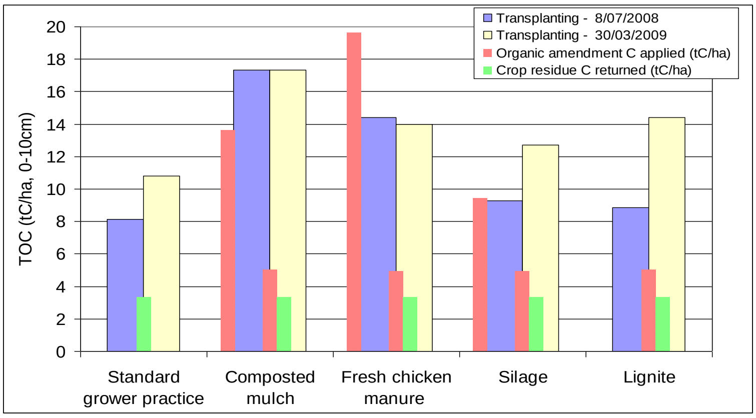


Fig. 6: Total organic carbon levels (TOC t C/ha) in the top 10 cm of soil at harvest of two broccoli crops over two seasons. Organic amendments were applied prior to transplanting of each crop.

(Quantities of carbon applied (t C/ha) in each amendment are shown by the red striped bars and carbon return to soil by crop residues shown by green striped bars**).**

The more rapid decomposition of the chicken and green manures, although resulting in lower soil carbon levels, has important benefits for the soil. The decomposition improves soil structure and releases plant nutrients (e.g. N) bound in the manures. All the organic amendments applied in this trial, except lignite, resulted in broccoli yields equal to or greater than standard grower practice. Fresh chicken manure gave the highest yields (Fig 7).

Effect of repeated organic treatments to soil on disease suppression and broccoli yields (Boneo, Victoria)

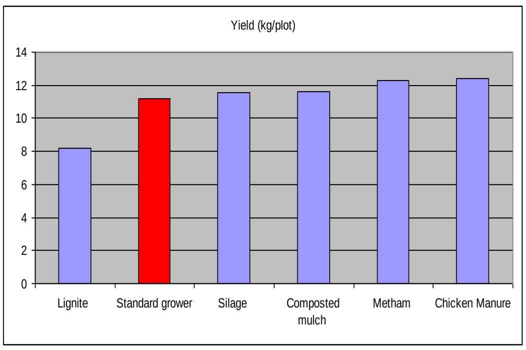


Fig. 7: Yield of broccoli under different long term organic matter management regimes

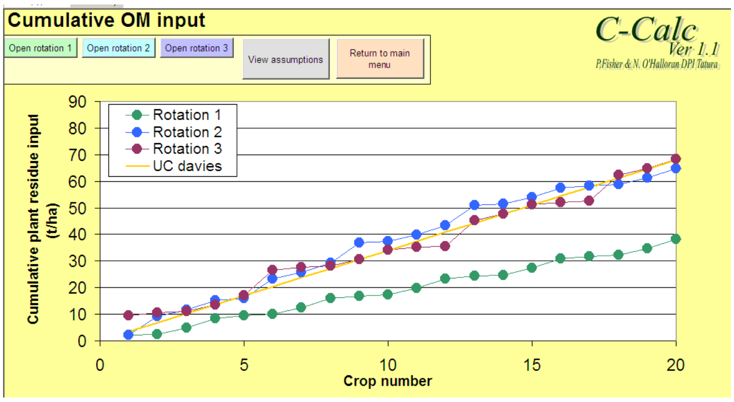
Treatment	Clubroot rating (0-3)
Standard	0.33
Metham	0.03
Compost	0.85
Chicken	1.65
Silage	0.15
Lignite	1.93

Adding repeated applications of organic matter @ 5 to 10 C/ha gave better yields than standard grower practice without organic amendments. Composted chicken manure and composted green organic waste consistently increased yields over 3 seasons.

When repeated over a 3 to 5 year time frame, the organic amendments should continue to provide better utilisation of fertiliser and improve soil structure through better crop water management resulting from increased infiltration and soil water holding capacity (Fig 3).

‘C-Calc’ - A tool to assist calculation of amount of organic matter added to soil

The amount of organic matter (OM) being returned to the soil is the single most important factor growers can control to influence soil carbon levels and ultimately soil health. “C-Calc” has been developed to estimate the carbon contribution added to the soil from rotations or amendments and allows growers to compare different practices without actually growing a crop. C-Calc was originally developed with GRDC funding for the grains industry, and has been revised for the vegetable industry with HAL funding.



C-Calc shows a line of the cumulative level of organic matter entering the soil from crop residues, roots and applied amendments over the period of the rotation. In the long-term, a rotation that provides more OM to the soil is likely to result in a higher soil carbon level and better soil health. C-Calc does not predict the actual change in soil carbon percent as obtained from a soil test. Soil “carbon models” are able to predict these effectively, but they require a lot of information on the climatic conditions and the rate of carbon decay in the soil, and are complex to use. Until such tools are readily available to growers, C-Calc provides an indication of the more effective crop rotations and practices.

InfoLeaflets

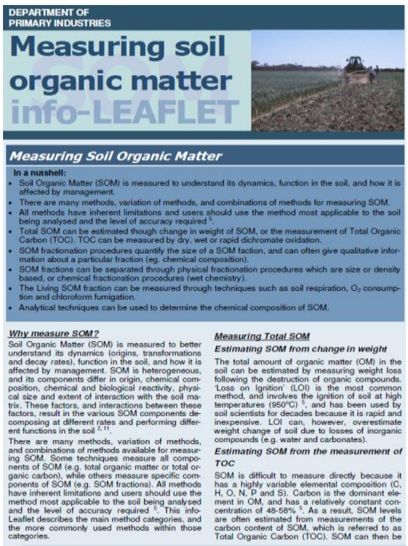
General information on soil organic matter (SOM) is available from a wide range of sources, such as:

- The Ute Guide
- Soil Quality: www.soilquality.org.au/
- Soil Health Knowledge Bank: www.soilhealthknowledge.com.au
- DPI Vic: www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-home
- DPI NSW: www.dpi.nsw.gov.au/agriculture/resources/soils
- The Cornell University: www.hort.cornell.edu/soilhealth/

Most of this information is intended for a general audience. For greater depth of knowledge, consultants, agronomists, scientists, students and interested growers have had to access papers published in technical journals or text books. The DPI Victoria “Soil Organic Matter Info-Leaflets” have been developed to bridge this gap between general information and scientific literature. In a series of four-page leaflets, greater explanation of our current knowledge on the functioning, benefits, and measurement of SOM is described in plain English. The current “SOM Info-Leaflets” cover:

- Measuring Soil Organic Matter
- Soil Organic Matter Fractions
- Modelling Soil Organic Matter
- Soil Organic Matter and Soil Biota
- Soil Organic Matter and the Carbon Cycle
- Soil Organic and Nutrient Cycling

As well as providing greater depth of information these Info-Leaflets explain many of the confusing aspects of SOM that have arisen due to the different approaches and measurement techniques that have been used around the world.


DEPARTMENT OF PRIMARY INDUSTRIES

Measuring soil organic matter info-LEAFLET

Measuring Soil Organic Matter

In a nutshell:

- Soil Organic Matter (SOM) is measured to understand its dynamics, function in the soil, and how it is affected by management.
- There are many methods, variation of methods, and combinations of methods for measuring SOM.
- All methods have inherent limitations and users should use the method most applicable to the soil being analysed and the level of accuracy required [5].
- Total SOM can be estimated though change in weight of SOM, or the measurement of Total Organic Carbon (TOC). TOC can be measured by dry, wet or rapid dichromate oxidation.
- SOM fractionation procedures quantify the size of a SOM faction, and can often give qualitative information about a particular fraction (eg. chemical composition).
- SOM fractions can be separated through physical fractionation procedures which are size or density based, or chemical fractionation procedures (wet chemistry).
- The Living SOM fraction can be measured through techniques such as soil respiration, O_2 consumption and chloroform fumigation.
- Analytical techniques can be used to determine the chemical composition of SOM.

Why measure SOM?

Soil Organic Matter (SOM) is measured to better understand its dynamics (origins, transformations and decay rates), function in the soil, and how it is affected by management. SOM is heterogeneous, and its components differ in origin, chemical composition, chemical and biological reactivity, physical size and extent of interaction with the soil matrix. These factors, and interactions between these factors, result in the various SOM components decomposing at different rates and performing different functions in the soil [2, 11].

There are many methods, variation of methods, and combinations of methods available for measuring SOM. Some techniques measure all components of SOM (e.g. total organic matter or total organic carbon), while others measure specific components of SOM (e.g. SOM fractions). All methods have inherent limitations and users should use the method most applicable to the soil being analysed and the level of accuracy required [5]. This info-Leaflet describes the main method categories, and the more commonly used methods within those categories.

Measuring Total SOM

Estimating SOM from change in weight

The total amount of organic matter (OM) in the soil can be estimated by measuring weight loss following the destruction of organic compounds. ‘Loss on Ignition’ (LOI) is the most common method, and involves the ignition of soil at high temperatures (950°C) [5], and has been used by soil scientists for decades because it is rapid and inexpensive. LOI can, however, overestimate weight change of soil due to losses of inorganic compounds (e.g. water and carbonates).

Estimating SOM from the measurement of TOC

SOM is difficult to measure directly because it has a highly variable elemental composition (C, H, O, N, P and S). Carbon is the dominant element in OM, and has a relatively constant concentration of 48-58% [5]. As a result, SOM levels are often estimated from measurements of the carbon content of SOM, which is referred to as Total Organic Carbon (TOC). SOM can then be

Soil Health Management Plan

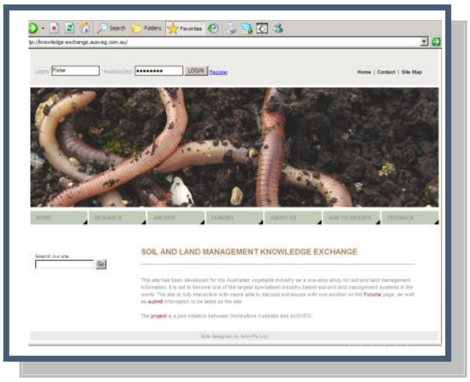
1. Know your soil (Prepare a soil map of property or soil pit)
2. Soil Analyses (Physical, chemical and biological tests) • Penetrometer testing to identify compaction issues • Consider a water infiltration test • Soil analysis for macro and micronutrients every 1-2 years • **Plant nutrient analysis** at flowering • Soil labile carbon test every 3 years
3. Rational use of inputs - water, fertiliser, pesticides, fumigants using threshold guides to avoid overuse
4. Organic matter management ▪ Green manure crops to increase OM (Rye corn, Sudan grass, etc.) ▪ Local compost
5. Avoid soil compaction ▪ Modify equipment (lightest possible, wider tyres, low tyre pressures) ▪ Implement controlled traffic ▪ Use crop rotations ▪ Avoid working saturated soils
6. Minimise soil erosion ▪ Reduced tillage ▪ Permanent cover crops

Key websites

1. http://knowledge-exchange.ausveg.com.au - Vegetable Industry Soil Health Knowledge Exchange

2. http://soilquality.org.au/. Soil Quality Website, WA.

3. http://soilhealthknowledge.com.au/ Soil Health Knowledge Bank



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11 Discussion and Conclusions

In 2008 when this project was commissioned, the team of researchers on this project were challenged by industry to determine what benefits could be obtained for growers by investment in soil health. In particular, the industry wanted to know how to manage organic and inorganic inputs (fertilizers, pesticides, organic amendments) to increase crop productivity sustainably.

The benchmarking studies discussed in this study (chapter 4) identified that gathering information on chemical, biological and physical aspects of soil health is the first step towards good soil health management. Although only a small number of benchmarking sites were used in this study, they showed similar trends to those in the previous project (VG06090). This study identified that 71% of growers use excess fertilizers and therefore growers have great potential to increase profit by improving fertilizer use efficiency. This chapter also covered the importance of conducting paired site analyses to be able to determine the impact of one factor over another. It also identified the importance for the industry to identify threshold values for physical, chemical and biological parameters in regions throughout Australia so that they can make more precise conclusions. For instance, what are the fertilizer thresholds for application of fertilizer products to achieve good soil health? How much N is being leached in the different regions through groundwater and surface run off or through emissions to the atmosphere and how can these be mitigated? How does the excess P, S and N affect suppression/promotion of soilborne diseases? Some of these questions were answered later in the project, however it is recommended that any future research continues to model total nutrient balance within horticultural systems to identify areas to improve efficiency of use of fertilizers and reduce environmental impacts.

Further, the benchmarking chapter in contrast to the above results with the major macro nutrients showed that many other nutrient inputs in Australian vegetable production systems, although varying widely in different regions, are seemingly well matched to the crops requirements with the exception of nitrogen, phosphorus and sulphur. Conducting chemical tests and use of nutrient indicators prior to growing a crop is essential to growing a successful crop, but also for good soil health management and to avoid over fertilising and the resultant damaging environmental effects (ie nutrient losses to the atmosphere and off farm through leaching). The chemical and biological indicator tests also showed that when drawing conclusions from of the impact of common treatment practices (ie. organic verses conventional or fumigation verses no fumigation) a large number of samples (>6) are needed within each site treatment to overcome temporal and spatial variability with a treatments. This is because previous crop and soil (tillage) used prior to cropping have major disturbances which have a huge local influence.

The nematode faunal analysis confirmed that in general all vegetable farms in this study in temperate Australia show a similarity in enrichment and structure indices. They correctly showed that the biodiversity indices of structural index and enrichment index showed that the sites generally represented disturbed sites, with high N enrichment, and a low C:N ratio (Figure 4.3, Appendix 4.3). This is not unexpected as growers till and fertilise the soils routinely and unlike the tropical regions use very little minimal tillage to grow crops. The impact of these practices is to provide great variability in the outcomes from physical, biological and chemical tests and this stresses the importance of testing routinely at the same growth stages. In our study, three sampling times were kept constant, i.e. before treatments, at transplanting and at harvest. The aim for future programs is to see if growers are willing to transition parts of their farms to practices which cause less disturbance to see if they can then benefit from the resilience offered by more structured biological systems. For instance, can they build natural suppression of soilborne pathogens?

To maximise results from these soil health studies throughout Australia a database needs to be developed with data sorted by regions. Once established this database will start showing trends in production systems which can be altered to improve crop productivity. The Cornell University program is extremely successful because it has over 7,000 site entries from individual farms in NE USA and this compares to 100 conducted in the two studies so far conducted on benchmarking in temperate Australia. Any future study is encouraged to ensure that they standardise the tests and parameters with the studies on soil health already commissioned in Australia. Also, that this data be deposited in a central repository in the public domain so it can be used by others. Over time this will add to the knowledge and adoption of factors which improve soil health practices.

Laboratory and glasshouse trials conducted under controlled conditions in this study (Chapter 5) showed that :

- Adding carbon amendments to soil either decreased or increased inoculum of soil-borne pathogens. The outcome depended on the form and type of pathogen (eg sclerotia or hyphae, saprophytic ability) and carbon amendment added to soil (eg labile carbon content). For example, amending soils with vetch or biochar enhanced degradation of sclerotia of *S. minor* in soil. In contrast, adding compost, biochar, lignite and humate to soil increased concentrations of *R. solani*. We hypothesise that the stronger the saprophytic ability of a pathogen is, the more likely that its inoculum will increase following addition of carbon amendments into soil.

- Irrespective of the effect on inoculum, adding carbon amendments to soil had the capacity to decrease expression of specific soil-borne diseases in vegetable crops. Some other diseases are promoted by organic matter (see chapter 6). For example, adding humate and compost to soil reduced the incidence of damping-off in radish by up to 60%, even though this treatment increased the concentration of the pathogen in the soil. In these cases, disease suppression was probably due to an increase in specific groups of soil microflora that interfere with pathogenesis through antagonism.

- Amending soils with carbon inputs affected clubroot expression in brassicas by modifying soil pH. In particular, amendments that lowered pH, such as lignite, increased expression of clubroot. Such amendments may need reformulation or co-application with lime in soils where clubroot is a problem.

- There was a positive relationship between increased labile carbon and biological activity in soil. Furthermore, increased biological activity was associated with increased disease suppression of damping-off in radish and clubroot in broccoli.

The impact of carbon amendments on soil-borne pathogens and disease involves complex biological and chemical interactions. Vegetable growers need greater certainty of effects of organic amendments before they will widely adopt them for disease mitigation purposes. This will require greater knowledge of: (1) the mechanisms that drive disease suppression by organic amendments; and (2) the impact of specific amendments on specific crop/pathogen systems under specific environments and soil types. Results from this project can be built upon by continuing long term monitoring of the changes in soil biota and the chemical shifts in soil following amendment with carbon inputs. New molecular technologies are now available to make this next step (see chapter 5). This will require further research investment by industry, but ultimately the benefits will include: increased sustainability of production, more reliable disease control with reduced pesticide inputs, and increased carbon sequestration into soils.

Chapter 6 presented the results of trials which showed the effects of short and long term effects of pesticides, fertilizers and organic inputs into cropping systems.

During the 3 years, six large field trials identified:

- That different organic and inorganic inputs can increase yields by up to 15% and consistently increase profit by up to $3,000 to 6,000/ha per crop across a number of seasons.
- The best profit results were achieved when growers used stabilised fertiliser products, such as Alzon. It subsequent work it was shown that this product had lower emissions of N_2O to the atmosphere and consequently a potential for more available N for crop production.
- Also, the program showed that several products were being applied inefficiently and alternative methods could be used to increase crop performance:
    - For instance, growers in this region of Australia often apply large quantities of chicken manure to the surface of soil to stabilise the soil against wind erosion, however the nitrogen from the manure is lost through emissions or leaching down the furrows. During our trials, manures, which were either untreated or treated with nitrification inhibitors, were incorporated into soils and this proved to be a much more effective way of utilising the potential fertiliser value of the mulch. Surface erosion was also not an issue.
- Field trials also showed that organic products varied widely in their ability to promote crop productivity and disease suppression. This was dependent on the nutrient value, the carbon form (labile or inert) and the ability to produce organic toxins. Chicken manures, composted green wastes and biofumigants (eg. Fumafert) provided consistent gains in crop productivity of up to 10% compared to the grower standard conventional program.
- At one large commercial farm, trials also showed that a 20% reduction in irrigation resulted in a 5% yield gain for non-fumigated treatments.

In summary, the many studies in this report have shown that good soil health management is largely driven by the management of carbon (and the major macronutrients in soil, especially management of nitrogen) in the soil. Carbon provides both the food for soil organisms (good and bad) and helps build soil structure required for root growth and water storage. This study has shown that agricultural practices especially in the intensive vegetable production systems in temperate Australia significantly reduce soil carbon levels (Chapter 7 and 8) and this questions how much effort a grower should spend investing in building soil carbon without a change in production practices. A longitudinal study showed that continuous vegetable production can cause large declines in soil carbon – at one site it declined 66% over 7 years. A long term field trial at Boneo, Victoria (Chapter 6) in a typical coarse sand in the Mornington Peninsula showed that even with large amendments of soil carbon (5 to 10t C/yr) that only one product (i.e. lignite) showed signs of increasing soil carbon after 3 years of repeated application. Tillage (and possibly high N additions) appeared to be the major factor reducing carbon levels.

As mentioned, studies in the report showed that unless growers alter production systems towards less tillage, then little long term benefit will be gained from continual additions of organic matter particularly those with high labile C content (eg. chicken manure, green waste composts, silage). All products of this type were shown to be decomposed rapidly in highly tilled soils. Trials with products which contain more inert carbon (such as lignite, biochar, etc.) showed that it was possible to start building soil carbon, but that very long term studies (>10 years) are required to identify the potential benefits from these inputs. In this study, both positive and negative results were shown from use of lignite and biochar. Lignite promoted the germination of nettles and at high levels (2.5 – 5.0 t/ha) promoted the disease, clubroot. Biochar sometimes promoted disease and other studies reduced disease.

- A user friendly computer-based tool ('C-Calc') has been developed to help estimate the amount of organic matter that is being returned to the soil from different rotations and amendments.
- A series of six information leaflets on use of organic matter and soil health has also been developed.

The value and feasibility of a National benchmarking program for the Australian vegetable industry, similar to the soil health score card developed by Cornell University is currently being assessed. This would benchmark soil health information on parameters found in guides (eg soil health ute guide) for each district and this will be further explored in future projects.

12 Recommendations

- 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 mostly targeted 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.
- That studies continue to monitor the affect of newer sustainable practices on soilborne diseases, pests and weeds. During this study several important commercially applied organic amendments increased economically important diseases, such as clubroot. 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.
- That the industry consider investment into 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.
- 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.
- 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.
- That growers consider the following specific changes to their crop production as follows;

- Calcium nitrate applications at transplanting be replaced with ammonium based fertilizers (eg. urea based) preferably with 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.
- That incorporation of composted chicken manures be considered 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.
- That growers consider using alternative carbon and nutrient-based programs to control pest and diseases (e.g. pH modifiers for control of clubroot). 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 anymore than alternative grower practices.

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