Vegetable soil health systems for overcoming limitations causing soil borne diseases

Dr Tony Pattison
The Department of Agriculture, Fisheries and Forestry, Qld

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Vegetable Soil Health Systems for Overcoming Limitations Causing Soil borne Disease

June 2013

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The purpose of the report is to summarise progress in developing vegetable production systems with improved soil health that overcome soil limitations with the potential to suppress soil borne diseases. Management approaches to soil health improvement were regionally specific to overcome regional soil limitations in different production environments.

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1. Media summary

The vegetable soil health project aimed to find more sustainable methods for producing vegetables in Queensland and New South Wales. The project worked on long term field trials and commercial farms to determine how management could be improved to take advantage of greater soil biological activity and diversity, while economically producing vegetable crops. The focus in Queensland was on minimum tillage, organic mulch systems and how growers could switch from the intensive "plasticulture" systems, without suffering yield penalties. The work in New South Wales focused on nutrient management and the use of composted garden organics at a long term field trial at the Centre for Recycled Organic Agriculture in Camden.

The Australian vegetable industry is under increasing pressure to cut costs, improve product quality and protect environmental resources. The improvement of soil health is seen as a step to resolve these problems, although changes often require new knowledge, capital investment and greater risks. Vegetable growers are not willing to change management practices if there are penalties to production or product quality. The aim of this project was to develop a greater understanding of management practices that have the potential to overcome soil constraints and enhance biological activity and diversity.

There was a trend for increased soil organic matter in management systems that promote soil health. These systems produced equivalent yields to conventional systems, with greater produce quality. However changes in soil properties take time to occur and the full potential of such systems was not realised over the length of this project. Vegetable growers adopting new farming systems need to be aware of their particular soil constraints to vegetable production. When inputs are reduced there is a greater emphasis on soil processes to maintain productivity and quality. This requires modifications to machinery as well as management of nutrients and water during crop production. Vegetable production systems that increased organic matter in the soil appeared to be more durable to environmental stress allowing produce quality to be maintained.

This project made some progress towards understanding the effect of various management practices in vegetable production systems and the benefits of studying practice change in long-term field trials. However there is still a need for a greater understanding of soil biological activity and how this is affected by vegetable management practices. The development of new farming systems that promote soil health need to undertake regional development to ensure they are relevant to local producers and systems need to be flexible whilst under development to respond to new information as it becomes available and deal with challenges as they arise.

Important lessons were learnt during this project. When converting to minimum tillage systems growers should be aware that soil compaction may be a problem and consider zone tillage or specially designed equipment. More precise management of nutrients and water are required, particularly under organic mulch systems, which lose more soil moisture than plastic mulch. However, the benefits from the increased soil organic matter not only provide a more active and diverse soil biology but can improve the quality of vegetables.

2. Technical summary

Vegetable production typically uses multiple and aggressive tillage operations with little organic matter input. This can leave the soil in a degraded state, leading to negative impacts on soil health and fertility, with reduced crop production. Vegetable growers are seeking alternative methods of production that allow soil improvements, without penalties to production or quality. There is limited regionally specific information available to assist vegetable growers to convert to more ecologically based production systems. The aim of this project was to develop production systems that overcome soil constraints by developing vegetable systems with greater biological activity and diversity.

The project investigated different production systems via long term field trials, commercial sites and validation trials in Queensland and New South Wales. The long term field trials in Queensland investigated the use of minimum tillage, organic mulch systems compared to conventional "plasticulture" with intensive tillage. In north Queensland the first year of the trial highlighted soil constraints attributed to soil compaction and water and nutrient management. Once these constraints were overcome in the second year of the trial, equivalent yields of zucchini and capsicum were obtained and an increase in soil organic C led to an increase in capsicum fruit quality. The labile C fraction of the soil organic C was found to drive many biological processes in the soil leading to a reduction in soil compaction and plant-parasitic nematodes on a commercial site in north Queensland. The trial in south-east Queensland near Bundaberg did not yield the same results. In a best management vegetable practice system there was an increase in the number of predatory and omnivorous nematodes with an increase in vegetable production, which was consistent with reduced soil disturbance.

The long term field trial in NSW continued investigating the use of recycled organics. The addition of 125 dry t/ha of composted garden organics every 5 crops resulted in an increase in soil organic C, cation exchange capacity, available nutrients and structural stability compared with conventional farming practices. The application of compost initially increased soil biological activity, which diminished with subsequent vegetable crops grown. The high levels of P, commonly associated with vegetable production and waterway pollution in the Sydney basin, were found unnecessary for production. The application rate of composts and manures needs to take phosphorous loading into account, it is unadvisable to base limits solely on nitrogen.

This project highlighted the need for developing a greater understanding of soil ecology and the identification of soil constraints when developing new production systems. Due to the diversity of vegetable production and growing regions in Australia, solutions to declining soil health need to be regionally focused. Furthermore, changes to soil properties often take time to manifest themselves, meaning that little change to soil properties and crop production may be seen in the short term. By identifying and managing soil constraints, advances in vegetable production systems can be made. The building of soil organic C appears to be the key to building greater biological diversity and activity and consequently soil health.

The research undertaken in this project has increased our knowledge of soil ecological interactions and requirements for developing more sustainable vegetable production systems. The project also reports on lessons and primary recommendations that will support growers who decide to trial alternative production systems in vegetables.

However, further work is required to verify the studied systems for different vegetable crop species, to improve and develop the systems and assess the impacts of the practice changes over the long-term.

3. General introduction

The Australian vegetable industry is valued at over $3.3 billion, produced from approximately 5,753 farms (www.ausveg.com.au/statistics). Vegetable production centres tend to be located close to major capital cities, except for commodities where the climate and scale of operations provides a marketing advantage. However, the industry is constantly facing a cost-price squeeze and must address issues of economic and environmental sustainability, while retaining consumer confidence in the quality of produce (Price *et al.* 2005). The Australian vegetable industry is diverse; a large number of crops are grown on a range of soil types in various climatic zones using different production systems.

In vegetable production systems, the soil maintains essential functions by providing support for the plant, supplying water and nutrients, helping to suppress pests and diseases and degrading xenobiotics preventing them from entering the food chain. However, intensive vegetable production has largely ignored the ecosystem functions of the soils supporting agriculture, instead focusing on an industrialised production model which utilises external inputs (irrigation, fertilisers, chemical pest control) to achieve production goals (Hendrickson *et al.* 2008). Anderson *et al.* (2007) describe nine different soil type classes used for vegetable production in Australia ranging in texture from heavy clays to sands. Soil management practices in vegetable production usually aim to overcome the most limiting soil constraints, such as poor nutrient supply, compaction or pest and disease problems (Moody and Cong 2008; Sanchez *et al.* 2003). Regardless of soil type, crop or region, these practices focus on management of traffic and tillage, nutrients and organic matter.

There is an increasing emphasis on designing new systems which focus on natural environmental process to sustain crop productivity (Malezieux 2012; Médiène *et al.* 2011; Scopel *et al.* 2013). The new systems promote active and diverse soil biology through increasing organic matter inputs and reducing soil disturbances. Management practices to improve or stabilise organic matter content of soils were listed by Fageria (2012) as:

i. Conservation tillage
ii. Crop rotation
iii. Use of adequate fertiliser
iv. Liming of acid soils
v. Use of organic manures
    a. Cover crops / green manures
    b. Farm yard manures
    c. Municipality compost
    d. Recycling crop residues
vi. Keeping land under pasture

One or more of these practices may be appropriate for a given production system. Practicality and the ease of implementation is dependant on the vegetable crop being produced and the proximity of farms to relevant resources, like municipal composts and animal manures. By introducing appropriate practice changes to a production system, major improvements to soil health under vegetable production are expected but not guaranteed. It is possible to offset practices that improve soil health by practices that degrade soils. For example, the use of green manures may increase

organic matter inputs, but over cultivation of the green manure crop may rapidly increase organic matter decomposition reducing the benefit to soil health.

Conservation tillage aims to minimise loss of soil and water by reducing tillage or using a planting sequence that leaves 30% or more of the crop residue on the soil surface (Fageria 2012; Scopel *et al.* 2013). The amount and type of tillage is known to impact on physical, chemical and biological soil properties (Bandick and Dick 1999; Hoyte *et al.* 1994; Morris *et al.* 2010; Stirling and Eden 2008). In recent years there has been an increase in research looking at the use of minimum tillage in modern vegetable production systems (Brainard and Noyes 2012; Rogers *et al.* 2004; Stirling 2008; Wells *et al.* 2000).

Crop rotation is defined as a planned sequence of crops, grown in regular succession on the same area of land (Fageria 2012). Improved disease suppression has been found with longer crop rotation sequences due to an increase in an active and diverse soil biology, which promotes disease antagonists (Peters *et al.* 2003; Smith *et al.* 2011).

Past work has focused determining fertiliser application rates to optimise production. However, the focus of current research is to maximise production without impacting on the off farm environment (Chan *et al.* 2007; Dogliotti *et al.* 2004).

Organic carbon can be managed in the soil via practices like the growing of green manure crops and the application of organic amendments (Chan *et al.* 2008; Chaves *et al.* 2005; Rotenberg *et al.* 2005; Schutter *et al.* 2001; Srivastava *et al.* 2007). The addition of extra organic matter is typically aimed at maintaining or enhancing the organic carbon content of soils to improve soil structure and nutrient cycling and induce pest or disease suppression (Stirling 2008; Stirling and Pattison 2008).

Indicators related to soil properties are measured to detect changes in soil properties induced under different management practices. Soil monitoring indicators represent particular soil constituents, processes or conditions (Burns *et al.* 2006; Idowu *et al.* 2008). Soil health cannot be summarised by a single measurement, therefore, its assessment must include information from several indicators. Criteria for indicators of soil health relate mainly to the ability to define ecosystem processes, their ability to integrate physical, chemical and biological properties and their sensitivity to management (Benedetti and Dilly 2006; Idowu *et al.* 2008; Shukla *et al.* 2006). Soil health indicators have been used in other agricultural production systems to determine the best set of practices to improve soil management (Andrews *et al.* 2002; de Lima *et al.* 2008; Lilburne *et al.* 2004; Pattison *et al.* 2008; Shukla *et al.* 2006; Stamatiadis *et al.* 1999)

Several studies have compared organic or best practice systems with conventional production systems where multiple soil management practices have changed (Andrews *et al.* 2002; Moeskops *et al.* 2010; Srivastava *et al.* 2007; Wells *et al.* 2000). The adoption of the systems or elements of a system, often reflect the socio-economic status, goals and aspirations of the soil manager, as well as their knowledge of alternative practices and systems (Brodt *et al.* 2006; Lobry de Bruyn and Abbey 2003; Vanclay 2004). Responses to future challenges in agricultural production should include the development of systems that are productive, minimise their impact

on the environment, use renewable resources and are sympathetic with the goals of the land managers (Hendrickson *et al.* 2008; Médiène *et al.* 2011).

Rogers *et al.*(2004) developed no-till vegetable production systems for winter vegetable production in the Bowen / Burdekin region using *Centrosema pubescens* and *Bothriocloa pertusa* as cover crops. They found under the no-till system a reduction in soil bulk density, improvement in aggregate stability, increased earth worm numbers and equivalent crop yields compared to plastic mulch systems over 4 years. A seven step process was developed, from establishing and managing the cover crop, to growing the crop and preparing for the next cover crop (Rogers *et al.* 2004). However, further information was required to identify potential soil constraints and difficulties before growers were willing to adopt minimum tillage organic mulch systems. Also, more information is required on the biological interactions occurring under organic mulch compared to conventional intensive tillage with plastic mulch, in order to understand how soil biology can contribute to soil functions supporting crop production.

The initial aim of the research conducted in this project was to develop soil health systems that could overcome limitations caused by soil borne diseases. However, in many vegetable production systems soil borne disease is not the most limiting factor, or soil disease is a consequence of other soil limitations. Therefore, the project took a broader view of soil health to improve our understanding of soil limitations in vegetable production systems and to design and validate appropriate management practices to promote active and diverse soil biology with a view that suppression of soil borne disease would follow.

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4. North Queensland Field Trial

4.1. Summary

Introduction: Vegetable production typically uses multiple and aggressive tillage operations with little organic matter input. This can leave the soil in a degraded state, leading to negative impacts on soil health and fertility, and reduced crop yields. Vegetable growers are seeking alternative methods of production that allow soil improvements, in which they are not penalised in production or quality of produce. In the Dry Tropics region of North Queensland, the use of permanent bed systems with organic mulch is considered an alternative to intensive tillage systems that rely on plasticulture (use of polyethylene mulch and drip tape, both replaced and disposed of every year). The aim of these trials was to determine if vegetables could be effectively produced in systems that are an alternative to intensive tillage with plasticulture and to see if soil health could be improved. *Method:* A large field trial was established in Bowen. In 2011, the conventional system with intensive tillage and plasticulture (IT) was compared with a permanent bed system with organic mulch produced from a summer sorghum cover crop, and with buried drip irrigation tape and no soil disturbance (PB_{nsd}). In 2012, the same conventional IT system was compared with a permanent bed system which was prepared as PB_{nsd} but had minimal soil disturbance produced by zone tillage (PB_{zt}), and a hybrid system, which had permanent beds prepared as PB_{zt} but had plastic mulch laid on top of the beds (PB_{poly}). The plots for each system were split, with half receiving an annual application of 15 t/ha of compost and half not. Measurements were taken of soil physical, chemical and biological properties, three times in an annual cropping cycle, as well as agronomic characteristics of capsicum and zucchini, and the inputs used to grow them were recorded. *Results and discussion*: In 2011, fertiliser inputs were kept the same in all treatments but irrigation volume was greater in PB_{nsd}. Compared to IT, PB_{nsd} had marketable yield reductions of 70% for capsicum and of 30% for zucchini. Soil compaction was determined to be the major soil constraint in PB_{nsd} along with water and nutrient management. In 2012, the narrow zone tillage was performed in PB_{zt} and PB_{poly} using a wavy disc cultivator along the row where vegetable seedlings were subsequently transplanted. This minimum tillage had the effect of reducing soil resistance to penetration in the top 15 cm throughout the cropping season. There was no significant yield difference among the three tillage systems. Greater amounts of irrigation water and lower amounts of fertiliser were used in the minimum tillage systems PB_{zt} and PB_{poly} compared to IT. The addition of compost increased soil organic C and the proportion of predatory nematodes in the soil, and led to greater production of extra large capsicum fruit and reduced the number of misshapen fruit compared to IT. *Conclusion*: The permanent bed system using organic mulch PB_{zt} has the potential for equivalent production to conventional IT systems, but requires specific farming equipment and management to overcome soil constraints like compaction. PB_{poly} could be improved using biodegradable mulch and could be an alternative permanent bed system to PB_{zt} but with a lower requirement of irrigation water. The increase in soil organic C that may result from adding compost has the potential to improve soil conditions for plant growth and thus lead to greater production of quality fruit.

4.2. Introduction

Vegetables grown in the dry tropics areas of Queensland are an important supply for winter markets in the southern metropolitan areas of Australia. High-value vegetables are grown during the typically dry season (March-November) in approximately 8,321 ha. The main crops in the region are tomatoes, capsicums, beans, sweet corn, melons, zucchini, squash and pumpkin (Table 4-1). The production of vegetables in this region relies on broad scale operations often with small profit margins as growers fulfil contract obligations to large supermarkets (Chellemi and Porter, 2001). Therefore, producers require resource efficiency and cannot afford small drops in production.

Table 4-1: Vegetable production statistics in Northern Dry Tropics (Longford Creek to Giru).

Crop	Area (ha)	Production (t)	Gross ($M)
Tomatoes	1,800	108,000	148.3
Capsicum	1,380	51,888	107.1
Beans	450	40,050	68.1
Sweetcorn	1,900	19,000	33.6
Rockmelon & Honeydew	960	28,800	27.0
Watermelons	660	23,100	20.6
Zucchini & Squash	282	5,640	10.7
Pumpkins	550	13,750	8.4
Eggplant	245	6,003	7.2
Veg - processing	-	12,882	6.4
Chillies	12	24	2.1
Cucumbers	57	1,140	2.0
Sweet chillies	25	750	1.6
Total	**8,321**	**311,026**	**443**

Acknowledgments: Compiled by Tom Mullins and Siva Subriamaniam (DAFF, Bowen Research Station), April 2010.

The most common method of producing vegetables in many parts of the world involves frequent and aggressive cultivation to prepare land and form planting beds, as well as the use of plastic mulch with water and nutrients delivered by trickle irrigation systems (plasticulture) (Stirling, 2008; Stirling and Eden, 2008). The intensity of this tillage practice has left many soils in degraded state following consecutive years of vegetable production (Chan et al., 2008; Stirling, 2008). The maintenance of soil health and quality has been recognised as an important aspect of vegetable production (Abawi and Widmer, 2000; Chan et al., 2008; Wells et al., 2000). The advantages of improving soil quality are enhanced nutrient cycling, greater plant available water, unrestricted root growth and suppression of pests and diseases (Ewing and Singer, 2012). Soil organic matter and decomposition is the key. It is the degradation of soil organic matter that gives soil its beneficial properties (Janzen, 2006), but the degradation of soil organic matter pools leads to a decline in soil functions and quality (Weil and Magdoff, 2004). Therefore, there needs to be sufficient organic matter in the soil to sustain a level of degradation that allows soils to function and to promote crop production.

Conventional methods of land preparation in vegetable production systems involve multiple tillage systems to invert the soil and bury crop residues. This allows rapid

oxidation of organic matter (Franzluebbers, 2004; Morris et al., 2010). An alternative to conventional inversion tillage is conservation tillage, which aims to reduce losses of soil and water (Unger and Blanco-Canqui, 2012). The advantages of conservation tillage methods that have been reported include improved physical soil characteristics (increased aggregate stability, reduced compaction and water infiltration), altered soil chemical cycles allowing greater nutrient storage and improved biological characteristics as organisms recycle nutrients from organic matter leading to greater biological activity and diversity which are linked to disease suppression (Stirling et al., 2011; Unger and Blanco-Canqui, 2012). However, Unger and Blanco-Canqui (2012) suggest that in poorly structured soils with low organic matter no-tillage can lead to higher soil strengths, which may limit root growth and crop yields.

As well as conserving soil organic matter further inputs can be used in vegetable production. Cover crops play an important role in conservation agricultural systems, protecting the soil against erosion from wind and water and increasing organic matter inputs, improving soil structure, altering soil temperature and water, recycling nutrients and providing weed control (Unger and Blanco-Canqui, 2012). There is a wide range of cover crops available for the vegetable industry depending on climatic areas. Forage sorghum (*Sorghum sudanense*) is used in some vegetable production systems to, as a fallow crop, provide soil protection during the summer months and suppress soil borne pathogens (Finney et al., 2009; Mojtahedi et al., 1993). Furthermore, organic amendments such as composts can be used as an organically rich medium to improve degraded soils (Chan et al., 2008).

Polyethylene materials are commonly used in intensive tillage systems with vegetables and include mulch films to cover the planting beds and drip irrigation tapes. These inputs have many advantages for crop production but unfortunately they are replaced and disposed every year and are not recycled. Biodegradable mulches are now available for use in vegetable crops, although their adoption by growers is very limited.

There is a need to investigate and validate alternate cropping systems for the production of vegetables in North Queensland which incorporate conservation tillage systems. The systems need to show productivity, stability, resilience to pest and disease attack, energy efficiency and sustainability (Malezieux, 2012). In North Queensland there are examples of zucchini crops grown under permanent beds that are renovated every 5 years. Soils on one farm have organic C levels that range from 1.5-2%. This is uncommon in the Dry Tropics, as most vegetable farms under intensive tillage have organic C levels <1% due to the rapid decomposition of organic material. There are no commercial farms where crops like capsicum or tomato are grown under permanent bed and minimum tillage systems.

It is hypothesised that a productive vegetable system can be developed for the dry tropics based on reduced tillage and permanent beds with a summer fallow cover crop producing organic mulch that is thought to meet the demands of productivity, environmental protection and soil quality improvement. To be adopted by growers, the alternative system needs to be cost effective, with marketable production equal or greater than conventional tillage systems. This research attempts to identify constraints and benefits involved in moving from a traditional intensive vegetable

production system to a less intensive conservation tillage system and to develop solutions that enable economic vegetable production while improving soil health.

4.3. Methods

a. *Site description*:

The field trial was established in September 2010 at the DAFF Bowen Research Station (Figure 4-1). The soil type in the 5632-m^2 trial site was classified as Dermosol, which had a silty loam texture. The top 50-cm soil was light to dark brown in colour and reasonably uniform across the trial site. Below 50 cm, the soil became reddish-brown.

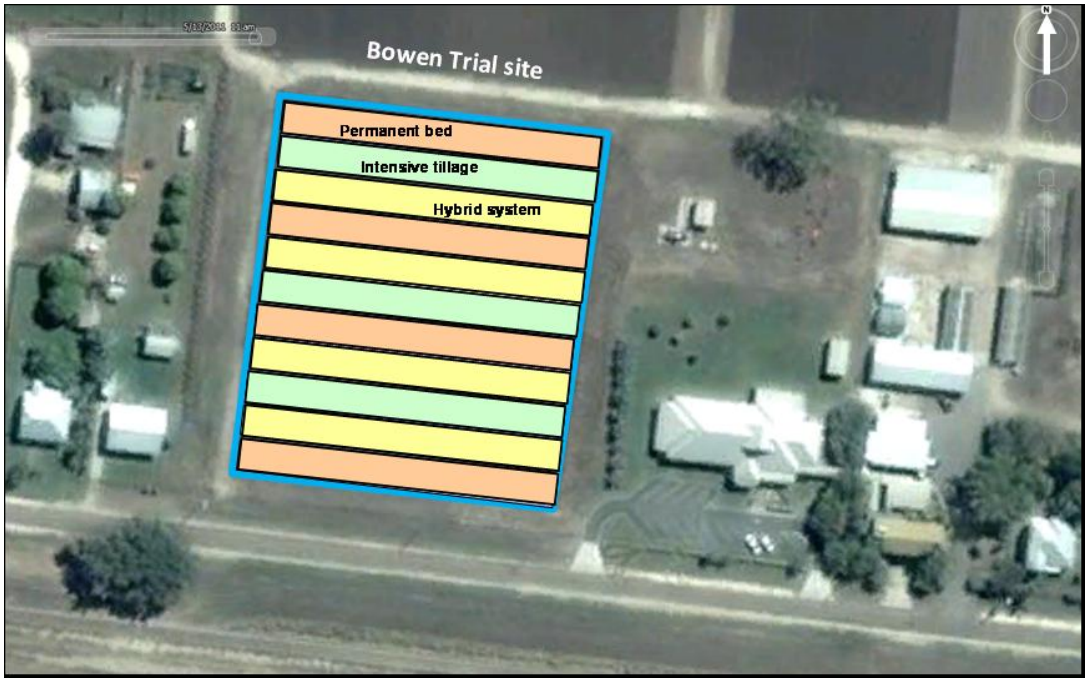


Figure 4-1: Trial location and layout at the DAFF Bowen Research Station. Treatments as of 2012.

b. *Treatment description*:

The distinction between soil management systems was based on tillage, cover crop management, the type of surface mulch and application of compost. The three main treatments include a different set of management practices:

1. **Intensive Tillage system (IT)** represents the scenario of a conventional practice with vegetables. The IT system comprised of multiple tillage operations, no-controlled-traffic, broadcast summer cover crop (forage sorghum), annual drip irrigation and black polyethylene mulch deployment on the beds used to establish the vegetable crops. The sorghum was slashed once during the summer and later it was slashed, sprayed with herbicide, and incorporated into the soil with multiple tillage passes before the drip tape and polyethylene mulch were laid. In 2011, there was an additional intensive tillage treatment **(IT_{lc})** that had two less passes of disc cultivators than IT before the beds were formed, thus creating not as much soil disturbance as IT. The IT_{lc} treatment was discontinued in 2012.

2. The **Permanent Bed systems**, are scenarios for an aspirational farming system, and were comprised of reduced tillage, with beds to be renovated (tilled and reformed) every 5 years, controlled traffic farming, summer cover crop (forage sorghum) and organic mulch, and sub soil surface drip irrigation tape buried for the 5-year period. In 2011, the soil in permanent beds was not disturbed (**PB_{nsd}**). In 2012, zone tillage, 5cm wide and to depths of 25 cm along the lines to be planted, was performed using wavy disc cultivators (**PB_{zt}**). No polyethylene or biodegradable mulch was used, but the residue from the cover crop slashed and killed with herbicides was left on the top of the beds to create organic mulch that can suppress weeds in combination with the use of herbicides.
3. The **Hybrid system (PB_{poly})** was considered a scenario of best practice or of transition of practice change, and is characterised by planting beds established as with the permanent bed system with zone tillage and subsurface drip irrigation (same as PB_{zt}) but with annual deployment of polyethylene or biodegradable mulch.

Table 4-2. Treatments in the field trial in Bowen and changes implemented in 2012 after identifying production constraints in 2011.

Year 2011[1]	Year 2012
Tillage	**Tillage**
Intensive Tillage **(IT)**	Intensive Tillage **(IT)**
Intensive Tillage less cultivation **(IT_{lc})**	Hybrid System **(PB_{poly})**
Permanent Bed no soil disturbance (**PB_{nsd}**)	Permanent Bed zone till (**PB_{zt}**)
Soil amendment	**Soil amendment**
Compost (15 t/ha)	Compost (15 t/ha)
No compost	No compost
Crop species	**Crop species**
Capsicum ("Warlock", Seminis Seeds)	Capsicum ("Warlock", Seminis Seeds)
Zucchini ("Nitro", SPC Seeds)	Zucchini ("Nitro", SPC Seeds)

[1]Beds were renovated at the end of 2011 to include changes implemented in 2012. The changes were implemented to address the constraints that limited production in permanent beds in the first crop season.
[2]Treatments in 2012 are proposed for repetition of the trial in subsequent years.

A summary of treatments in 2011 and 2012 is presented in Table 4-2. The experimental design was laid out as a split-split-plot, with three *tillage* treatments as main plots: 1) Intensive tillage (IT) (also with IT_{lc} only in 2011), 2) Permanent bed tillage system (PB_{nsd} in 2011 and PB_{zt} in 2012), and 3) Hybrid system (PB_{poly}) started in 2012. The main treatments were further split into two sub-plots, based on *soil amendment*: one with an application of compost (composed of sub products of the local sugar industry) at a rate of 15 t/ha and the second one which did not have compost application. Each main plot is 80 m long, while sub-plots were 40 m long, both having 4 planting beds distanced 1.6 m between centres. Due to land constrains (i.e. availability of land that had similar soil properties at the start of the trial), the design was unbalanced, with PB_{poly} and PB_{nsd} or PB_{zt} treatments replicated four times and the control (IT) replicated three times. The sub-plots were further divided into *crop species* (creating a sub-sub plot but not randomised within subplot), with two planting beds 40-m long to be planted with zucchini and two beds 40-m long with capsicum. The beds were replanted to the same crops each year. A copy of the 2012 trial layout is displayed in Figure 4-2.

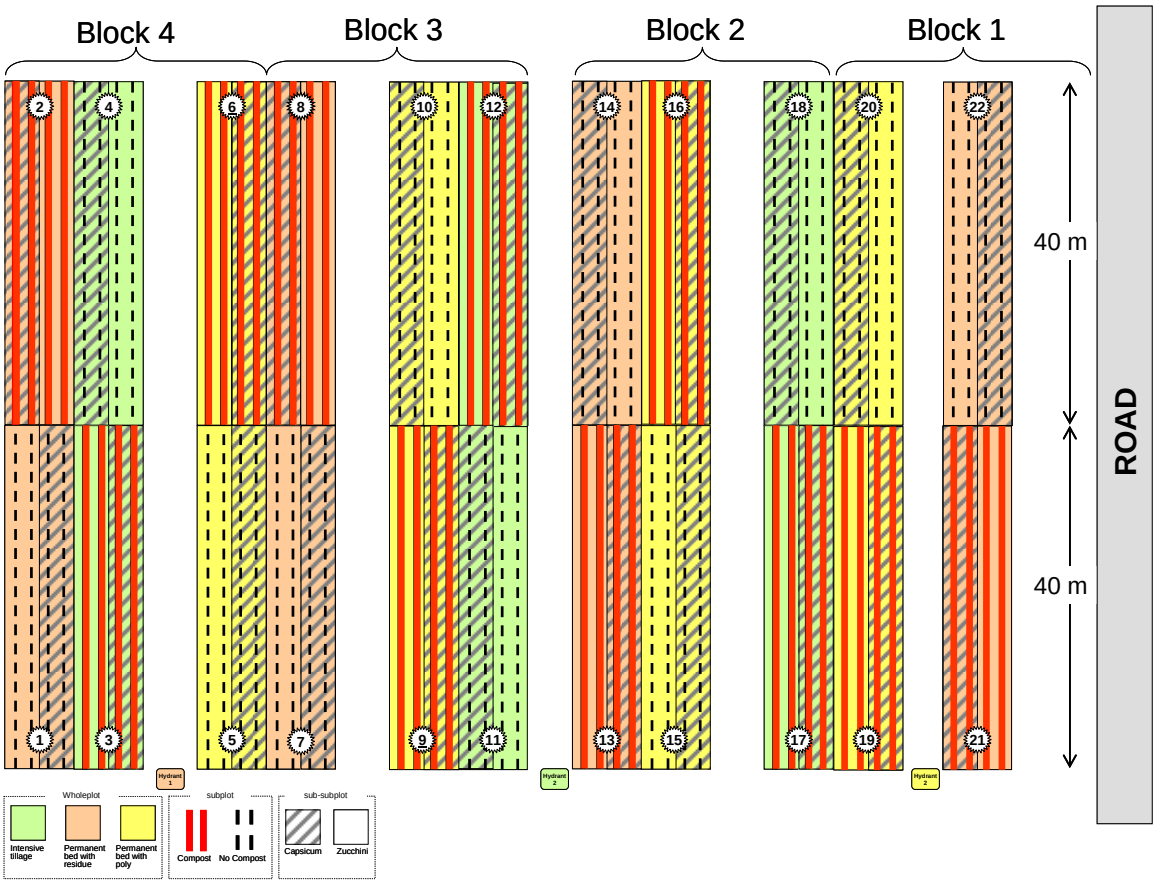


Figure 4-2: Design and layout of the field trial used to investigate long term land management practices on vegetable production at the DAFF Bowen Research Station. Treatments as of 2012.

The compost application was done just before planting the sorghum in November 2010 and 2011. The compost was based on by-products from the sugar cane industry (mill mud and bagasse).

c. *Sampling description*:

Initial sampling occurred in October 2010, at the beginning of the fallow period, composite soil samples from the top 0-15 cm soil profile were collected at four different points within each sub-plot. The samples were processed for physical, chemical and biological soil characteristics. Chemical analysis of soils was conducted by Incitec Pivot laboratories for standard nutrient analysis as well as soil particle size analysis (OM, OC, pH, EC, NO_3, P, PBI, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, SO_4, sand, silt and clay)[1]. Chemical analyses were also conducted on the compost used in the trial. Biochemical analysis of soil samples were conducted at the DAFF Centre for Wet Tropics Agriculture and included soil enzymes, labile C and soil nematode community analysis (pH, EC, FDA, β-glucosidase, Labile C, nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators), diversity, enrichment, structure and channel indices).

[1] " Incitec Pivot Fertilisers - What is Nutrient Advantage?." Incitec Pivot Fertilisers - IPFHome. N.p., n.d. Web. 26 Mar. 2012. <http://www.incitecpivotfertilisers.com.au/en/Soil%20,-a-,%20Plant%20Tests/Nutrient%20Advantage.aspx>.

Soil pH was determined in a 1:5 (soil:water) mix and measured using a pH multi probe. Labile carbon contents were determined by the amount of C oxidised by 33mM $KMnO_4$ in duplicate 5 g sub-samples using the method described by Moody and Cong (2008). Similarly, fluorescein diacetate (FDA) hydrolysis rate was determined from duplicate 5 g sub-samples using a modified version of the method initially proposed by Schnürer and Rosswall (1982). β-glucosidase was determined with the procedure published by Eivazi and Tabatabai (1988) except the toluene was substituted with 0.1% Tween solution and the modified universal buffer was replaced with a McIlvaine buffer (pH 6.0).

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g sub-sample of field moist soil was weighed onto a mesh sieve with a single ply of tissue and placed into a tray with 250 mL of water for 48 hours. The nematodes were collected on a 25 µm sieve and backwashed into a vial. The total number of nematodes was estimated and a 50 µL aliquot was placed on a glass slide. A minimum of 100 individual nematodes were identified to genus for plant-parasites and family for free-living nematodes.

Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators). Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index and the ratio of bacterivores and fungivores calculated (Yeates and Bongers 1999). Additionally, the weighted functional guilds analysis concept was applied, without plant parasites to determine the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris *et al.* 2001).

d. *Soil penetration resistance*:

A soil penetrometer (DICKEY-John) was used by inserting into the soil and determining the maximum penetration resistance for 15 cm increments, 0-15, 15-30 and 30-45 cm down the soil profile. From each plot, 10 readings were taken in between plants and along the row of plants. The average for each depth increment within a plot was converted to a force unit (MPa). The penetration resistance was determined at planting and harvest each year of the experiment.

e. *Water and nutrient management:*

The volume of the irrigation water used was calculated by the number and length of time of irrigation events and knowledge of flow delivery rates and water pressure in the drip tape. Tillage treatments and crop species could be irrigated independently. Flow meters were installed in 2012 to confirm volumes obtained with the previous calculation method.

To monitor soil-water tension and have an indicator of crop stress and water use, tensiometers (GJKTech) were installed at three depths, 15, 40 and 60 cm, 40 days after planting (DAP) in zucchini and 32 DAP in capsicum in 2012.

The total amount of N-P-K nutrients applied was determined each year from the fertilisers used. In 2011 no pre-plant fertiliser was used and all nutrients were applied through drip irrigation as soluble products such as Flowfeed CO3 (20.9:8.6:16.2), potassium nitrate (13.0:0:38.3) and calcium nitrate (15.5:0:19.0). In 2012, the IT

treatment had a pre-plant fertiliser CK55 (13.5:15.0:12.5) incorporated into beds at a rate of 0.07 kg per liner metre. Subsequent fertiliser application in the IT and all of the fertiliser applications for PB_{zt} in and PB_{poly} were done with soluble grade fertilisers through the trickle irrigation system. Fertilisation schedules in PB_{zt} in and PB_{poly} were the same and were increased in 2012 to levels that would be comparable to the total amounts used in IT.

f. *Crop agronomic measurements*:

Dates for planting and harvesting zucchini and capsicum are indicated in Table 4-3. A conventional water-wheel transplanter was used for capsicum (planted in double rows spaced 39 cm apart) and zucchini (planted in a single row spaced 52 cm apart). Plant dry weight measurements were taken at the end of the cropping season. Marketable yields were determined for both zucchini and capsicum using commercial fruit classification standards. Harvested fruits that were unmarketable due to size or defects were recorded. Fertiliser applications and irrigation events were recorded for each crop and production system.

Table 4-3. Planting and harvesting dates for capsicum and zucchini at the trial in Bowen in 2011 and 2012.

	Capsicum		Zucchini	
	2011	**2012**	**2011**	**2012**
Seed to planting	35 d	35 d	20 d	20 d
Planting	15 June	21 June	15 June	13 June
Harvest	27 Sept	3 Oct	17 harvests (27 July to 29 Aug.)	19 harvests (23 July to 5 Sept.)
Days to harvest	104	104	42 d to first pick; 75 d to last pick; 33 d of harvest	40 d to first pick; 84 d to last pick; 44 d of harvest
Harvest interval			1.9 d	2.3 d

g. *Statistics*:

An analysis of the data was firstly conducted using REML mixed model as the experimental design was unbalanced in order to determine differences in means between treatments at each individual sampling time. The fixed model was composed of treatments *Tillage*, *Soil amendment* and depending on the timing of sampling also *Crop species*. The random model used was Plots/sub-plots and depending on crop Sub-sub plot. The replication of the trial was accounted for in the plot structure. Means were separated using the `vmcomparison` command, when greater than two means were to be separated.

A correlation analysis was performed on the data to remove variables that were derived from one another or highly correlated with an $r > 0.80$. If variables selected were correlated to one another the variable that was measured rather than derived indices remained in the analysis.

The uncorrelated means from the REML analysis were used in a forward stepwise Discriminant Analysis (DA) to determine the minimum number of variables required to separate the main factor groups such as tillage treatment, soil amendment or crop. For soil nutrient analysis data the values obtained from composite samples across replicates was used. A cross validation of the DA model was made using the leave-one-out (jack knife error) method. All statistical analyses were conducted using Genstat 14 (VSN).

4.4. Results

a. Soil parameters

The means from each soil sampling are presented for nutrients (Table 4-4), nematode community (Table 4-5) and soil biochemical analysis (Table 4-6). An asterix symbol is used to denote means where a significant difference existed either between *Tillage*, *Soil amendment* or *Crop species* treatments. The analysis of compost applied in November 2010 and 2011 is given in Table 4-7.

Table 4-4: IncitecPivot nutritional analysis of soils.

		Oct 2010		Jun 2011		Aug 2011		Jan 2012		Jun 2012		Aug 2012	
Sampling dates		**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**
Sand Coarse	%	9	0.5	9	0.5	10	0.5	5	1.3			9	0.5
Sand Fine	%	61	0.7	61	0.6	60	0.8	64	1.0	68	0.5	61	0.9
Silt	%	11	0.4	11	0.4	12	0.5	12	0.7	14	0.2	15	0.6
Clay	%	19	0.3	19	0.3	18	0.3	20	0.2	19	0.4	16	0.6
Organic Carbon	%	0.79	0.02	0.84	0.02	0.77	0.01	0.82	0.02	0.84	0.03	0.81*	0.04
pH	(1:5 w)	7.2	0.01	7.1	0.02	7.0	0.04	7.4	0.02	7.2	0.17	7.3*	0.12
Elect. Conductivity	dS/m	0.051*	0.001	0.095	0.002	0.188	0.016	0.092	0.003	0.160	0.035	0.161	0.011
Chloride	mg/kg	11	0.34	62	2.6	150	18	24	2.1	50	15	108*	12.2
Nitrate Nitrogen (NO3)	mg/kg	4.5	0.3	3.9	0.7	4.6	0.7	5.1	0.4	28	10	7.0*	2.7
Phosphorus (Colwell)	mg/kg	121*	10	112	6	103	4	165	10	160	18	155	21.5
Phosphorus Buffer Index (PBI-Col)		52.9*	1.9	52.5	1.8	49.3	1.6	76.0	1.4	61	1.4	60	5.1
Available Potassium	mg/kg	135	3	163	3	119	3	137	2			152*	12.6
Cation Exch. Cap.	Meq/100g	11.9	0.2	11.7	0.1			11.0	0.3	11.8	0.2	12.7	0.37
Calcium (Amm-acet.)	Meq/100g	7.27	0.16	7.42	0.08	7.88	0.09	6.92	0.20	7.3	0.11	7.79	0.26
Potassium (Amm-acet.)	Meq/100g	0.35	0.01	0.41	0.01	0.31	0.01	0.35	0.01	0.47	0.03	0.39	0.03
Magnesium (Amm-acet.)	Meq/100g	3.71	0.08	3.58	0.03	3.78	0.06	3.28	0.09	3.62	0.05	3.8	0.09
Sodium (Amm-acet.)	Meq/100g	0.14	0.01	0.31	0.01	0.67	0.03	0.42	0.01	0.43	0.02	0.76*	0.06
Copper (DTPA)	mg/kg	1.32	0.02	1.33	0.02	1.33	0.03	1.38	0.02	1.4	0.03	1.39*	0.05
Iron (DTPA)	mg/kg	32.1*	0.8	40.8	1.3	34.9	1.6	31.5	1.5	33	1.51	35.8*	1.61
Manganese (DTPA)	mg/kg	10.6	0.3	12.3	0.2	10.9	0.4	10.1	0.2	9.5	0.50	9.9	0.53
Zinc (DTPA)	mg/kg	1.70*	0.12	1.57	0.06	1.52	0.05	1.63	0.07	1.6	0.09	1.67*	0.09
Sulfate Sulfur (MCP)	mg/kg	2.3	0.10	7.5	0.02	20.0	1.35	5.6	0.50	8.9	2.27	11.9	1.8

Table 4-5: Nematode trophic groups and nematode community indices of soils.

		Oct 2010		Jun 2011		Aug 2011		Jan 2012		Jun 2012		Aug 2012	
		Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Total nematodes	100 g soil	633*	51	856	51	1012*	45	506*	114	896	52	468	
Parasites	100 g soil	30	9	110	34	118	19	30	7	158	29	54	
Parasites	%	5	1	11	3	12*	2	8*	2	25	3	17*	2
Rotylenchulus sp		11	4	8	3	43*	16	19	6	8	2	3	
Fungivores	100 g soil	424	41	386	28	510	30	104*	14	345*	22	208	19
Fungivores	%	67	2	47	3	50	2	28	3	33*	2	47	3
Bacterivores	100 g soil	170	14	263	31	247*	18	344*	105	337*	33	117	
Bacterivores	%	27	1	30	3	24*	1	55	4	33	2	27	3
Ba 1		82	10	170	25	121*	13	288	103	168*	22	61*	9
Ba 2		66*	6	81	10	106	8	53*	8	146*	22	56	7
Predator & Omnivores	100 g soil	8	2	97	12	137*	11	28	6	57	8	30	
Predator & Omnivores	%	1	0	12	2	14*	1	9	1	7	1	8*	1
Ca 4		0	0	0	0	1	0	0	0	11	2	0	0
Om 4		6	2	94	12	123	10	27	6	46*	6	28	3
Taxa		7.4	0.2	8.1	0.3	10.2*	0.3	8.9	0.4	11.6	0.3	10.8	0.4
Diversity H'		1.50	0.03	1.50	0.03	1.79	0.03	1.69	0.07	2.04	0.06	1.93	0.06
Enrichment		58	1	64	2	60*	1	78*	3	67	2	59	2
Structure		6	1	38	4	45*	2	40	4	40**	2	30	2
Channel		59	3	51	4	56*	3	22	4	37	3	53	5
Detrital		95	1	71	4	63*	2	79	3	63	4*	67*	2
Predation		4	1	23	3	29*	2	15	3	14	1	17*	1
Roots		1	0	5	3	8*	2	6*	2	22	3	16*	2

Table 4-6: Biochemical measurements of soils.

		Oct 2010		Jun 2011		Aug 2011		Jan 2012		Jun 2012		Aug 2012	
		Mean	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**
pH	(1:5 w)	7.0	0.02	7.0	0.03	7.3	0.05	-	-	7.1*	0.03	7.3	0.06
Electric Cond	dS m^{-1}	36	1	76	8	120	12	-	-				
Labile C	mg g^{-1}	0.25	0.01	0.24	0.01	0.21	0.01	0.21*	0.01	0.21	0.01	0.22	0.01
Fluorescein						6.9	0.4			6.1	0.5	6.5	0.2
diacetate (FDA)	mg kg^{-1} hr^{-1}	7.4	0.4	6.7	0.4			7.5	0.4				
β-glucosidase	µgPNG g^{-1} hr^{-1}	30.0	0.9	28.3	0.8	39.6	2.5	-	-	32.7	1.9	35.7	1.31
Aggregate stability	%							-	-				
Bulk density	g cm^{-3}	1.49	0.01	1.50*	0.02			-	-	1.25	0.01	1.32	0.02
Porosity	%	19	0.2	33	0.7			-	-	45	0.6	41.4	0.8
Water filled pore space	%	84.7	0.87	86.2	2.81			-	-	39	1.5	45.8	1.9

Table 4-7: Analysis of compost applied to sub-plots at Bowen Research Station in 2010.

Nutrient	Units	Analysis	Amount applied @ 15t/ha	
Moisture	%	5.8		
EC	dS/m	2.88		
pH		5.86		
C	%	6.1	915	kg/ha
N	%	0.6	90	kg/ha
P	%	0.81	122	kg/ha
K	%	0.32	48	kg/ha
Ca	%	1.5	225	kg/ha
Mn	%	0.35	53	kg/ha
Na	%	0.04	6	
Element availability				
Nitrate	mg/kg	170	2.6	kg/ha
Ammonium	mg/kg	32	0.5	kg/ha
Phosphate	mg/kg	34	0.5	kg/ha
Potassium	mg/kg	770	11.6	kg/ha
Calcium	mg/kg	4030	60.5	kg/ha
Manganese	mg/kg	1020	15.3	kg/ha
Boron	mg/kg	39	0.6	kg/ha
Silicon	mg/kg	226	3.4	kg/ha
Sodium	mg/kg	61	0.9	kg/ha
Heavy metals				
Arsenic	mg/kg	2	0.03	kg/ha
Cadmium	mg/kg	<1	<0.01	kg/ha
Zinc	mg/kg	74	1.11	kg/ha
Mercury	mg/kg	<0.01	<0.0002	kg/ha

First soil sampling fallow - October 2010, Year 1

The initial sampling of the trial site in October 2010 resulted in minor differences between the treatments, which were not significantly different between tillage treatments except the number of Ba2 bacterivores (Table 4-8). No other significant differences were found among the tillage systems. The application of compost significantly increased the electrical conductivity, Fe, P, PBI and total number of nematodes relative to the plots that did not receive compost (Table 4-8).

Table 4-8: Significant differences in soil variables either due to tillage system or the addition of compost in October 2010 at the initiation of the experiment.

		Tillage system			Compost addition	
Variable		IT	PB_{nsd}	IT_{lc}	+	-
Ba 2		46 a	55 a	92 b	-	-
EC	dS/m	-	-	-	0.054 a	0.047 b
Fe (DTPA)	mg/kg	-	-	-	34 a	31 b
$P_{(Colwell)}$	mg/kg	-	-	-	155 a	84 b
PBI-Col)		-	-	-	58 a	47 b
Zn (DTPA)	mg/kg	-	-	-	1.78 a	1.61 b
Total nematodes*	100 g soil	-	-	-	658 a	521 b

Nematode mean presented is back transformed from ln (x+1). Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{nsd} = Permanent bed system, IT_{lc} = Intensive Tillage with less cultivation; Cap = Capsicum, Zuc = Zucchini

Observations made on initial soil properties when the trial was established

1. *Soil physical and chemical analysis*:
    - There were no differences detected in soil texture in the top 15 cm of the soil over the trial site.
    - Organic C and nitrate N were low, but consistent over the trial site.
    - There appeared to be a high availability of K.

2. *Soil nematode community and biochemical analysis*:
    - There were greater Ba2 nematodes in the IT_{lc} system relative to the IT system
    - There were no other significant differences in nematode community structure between the different treatments.
    - Fungal feeding nematodes were the most dominant trophic group of nematodes at the trial site; followed by bacterial feeding, plant parasitic and predatory nematodes.
    - The diversity of soil nematodes was moderate, but there was a very low structure index, which suggested the site was highly disturbed with a poorly developed soil food web.
    - Most of the C entering the soil food web appeared to be coming through the decomposition of detritus, by fungal or bacterial activity.
    - Biochemical activity was low over the trial site, with no difference between treatments.

Second soil sampling at planting - June 2011, Year 1

At the planting of the first crop on the trial site there were no significant differences found between the addition of compost and the untreated areas. However, bulk density was significantly greater in PB_{nsd} relative to the IT treatment, with intermediate values in the IT_{lc} (Table 4-9).

Table 4-9: Significant differences in bulk density due to tillage system in June 2011 at planting of the first year of the experiment.

		Tillage system		
Variable		**IT**	**PB_{nsd}**	**IT_{lc}**
Bulk density	g/cm^3	1.41 a	1.56 b	1.49 ab

Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{nsd} = Permanent bed system, IT_{lc} = Intensive Tillage with less cultivation

Observations made on soil properties at planting in the first year.

i. *Soil physical and chemical analysis*:
    - There was no change in soil texture in the top 15 cm of the soil over the trial site, which remained consistent.
    - Organic C increased slightly from the previous sampling 0.79 to 0.84.
    - There was an increase in the amount of Cl in the soil increasing from 11 to 62 mg/kg.
    - All other chemical and physical measurements were consistent with values determined in the initial sampling (Table 4-4)

ii. *Soil nematode community and biochemical analysis*:
    - There were no significant differences in nematode community structure between the different treatments.

- There was an increase in the total nematode population extracted from the soil up from 633 to 856 nematodes per 100 g of soil. This was mainly due to an increase in the number of plant-parasitic and bacterivore nematodes increasing from 30 to 110 and 170 to 263 nematodes per 100 g of soil respectively.
- There was a decrease in the number of fungivores from 424 to 386 nematodes per 100 g of soil, but they still represented approximately 50% of the total nematode population.
- Diversity, enrichment, channel and root indices all remained approximately at the same level. The structure and predation indices increased, whereas the detrital index decreased relative to the previous sampling.
- All biochemical measurements were largely unchanged relative to the previous sampling.

Third soil sampling at harvest - August 2011, Year 1
At the zucchini harvest sampling in the first year there were significant differences in soil parameters amongst tillage systems and crop species (Table 4-10).

Table 4-10: Significant differences in biological soil variables due to tillage system in August 2011 when zucchini were harvested.

		Tillage system			Compost addition		Crop	
Variable		**IT**	**PB_{nsd}**	**IT_{lc}**	**+**	**-**	**Cap**	**Zuc**
Total nematodes*	100 g soil	433 b	290 a	379 b	-	-	-	-
Bacterivores	100 g soil	330 b	134 a	261 b	-	-	-	-
Bacterivores	(%)	29 b	18 a	26 b	-	-	-	-
Ba1		198 b	45 a	139 b	-	-	-	-
Omnivores & Predators	100 g soil	-	-	-	-	-	150 b	77 a
Omnivores & Predators	(%)	10 a	17 b	14 ab	-	-	17 b	11 a
Plant-parasites	(%)	-	-	-	-	-	8 a	15 b
Rotylenchulus sp.	100 g soil	-	-	-	-	-	3 a	83 b
Taxa		9.5 a	11.3 b	9.6 a	-	-	9.6 a	10.7 b
Structure index		36 a	52 b	46 ab	-	-	49 b	40 a
Enrichment index		65 b	54 a	62 b	61 b	59 a	-	-
Channel index		46 a	71 b	49 a	-	-	-	-
Detritus		76 b	52 a	64 ab	-	-	-	-
Predation		20 a	36 b	30 b	-	-	34 b	23 a
Roots		-	-	-	-	-	5 a	10 b
FDA		-	-	-	-	-	5.7 a	8.0 b
β-glucosidase		-	-	-	-	-	32.2 a	46.3 b

Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{nsd} = Permanent bed system, IT_{lc} = Intensive Tillage with less cultivation.

i. Tillage systems
The PB_{nsd} system resulted in a significant decrease in the total number of nematodes, number of bacterivores and their proportion of the nematode community, particularly Ba1 type nematodes. The reduction in the number of bacterivores resulted in a lower enrichment index and detritus index and a greater channel index in the permanent bed systems relative to the IT and the

IT_{lc} systems (Table 4-10). There was also a greater number of omnivores and predators, number of nematode taxa and structure index in the PB_{nsd} relative to the IT and IT_{lc}.

ii. Crop species

The crops grown also significantly influenced the soil parameters. Capsicums had a greater number and proportion of omnivorous and predatory nematodes and structure and predation indices. The zucchini crop had a greater number of plant-parasitic nematodes, particularly *R. reniformis*, increasing the root indices, an increased number of nematode taxa and increased soil enzyme activity both for FDA and β-glucosidase (Table 4-10).

Fourth soil sampling fallow - January 2012, Year 2

In the second year of the experiment the analysis determined significant differences between tillage systems using Ba2 bacterivores and the number of fungivores. The PB system had greater numbers of both types of nematodes relative to the IT and IT_{lc} (Table 4-11).

Table 4-11: Significant differences in soil variables either due to tillage system or the addition of compost in January 2012 before planting.

		Tillage system			Compost addition	
Variable		**IT**	**PB_{zt}**	**PB_{poly}**	**+**	**-**
Total nematodes*	100 g soil	-	-	-	450 b	282 a
Bacterivores	100 g soil	-	-	-	268 b	130 a
Ba 2	100 g soil	34 a	86 b	35 a	-	-
Fungivores	100 g soil	69 a	145 b	62 a	-	-
Plant-parasites	(%)	-	-	-	6 a	10 b
Roots		-	-	-	3 a	8 b
Enrichment index		-	-	-	85 b	72 a
Labile C	mg/kg	-	-	-	0.23 b	0.20 a

Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{zt} = Permanent Bed zone till, PB_{poly} = Hybrid system

The addition of compost significantly increased the total number of nematodes, number of bacterivores, enrichment index and the labile C content of the soil (Table 4-11). There was also a small but significant increase in the number of plant-parasitic nematodes where no compost had been applied increasing the index of root feeding nematodes relative to where compost had been applied (Table 4-11).

Fifth soil sampling planting – June 2012, Year 2

At planting of crops in the second year there were significant differences between tillage systems (Table 4-12). The total nematodes, Ba1 and Ba2 as well as the total bacterivores, fungivores, predators and omnivores in the IT system relative to the PB_{zt} and PB_{poly} (Table 4-12). There were a greater number of plant-parasitic nematodes under the PB_{zt} system relative to IT with PB_{poly} intermediate. The nematode indices reflected the differences in the trophic groups of nematodes with a greater activity of nematodes involved in the detrital cycle in the IT, and fewer nematodes feeding on the roots. However, the IT system had the lowest structure index, even though it had the most predators and omnivores present. The IT system also had a high soil nitrate-N, soil moisture, but the lowest pH (Table 4-12).

Table 4-12: Significant differences in soil variables either due to tillage system or the addition of compost in June 2012 before planting.

Variable		Tillage system		
		IT	PB_{zt}	PB_{poly}
Total nematodes*	100 g soil	1715 c	535 b	380 a
Bacterivores	100 g soil	684 b	126 a	127 a
Ba 1	%	304 b	63 a	53 a
Ba 2	100 g soil	328 b	24 a	35 a
Fungivores	100 g soil	758 b	122 a	110 a
Fungivores	(%)	42 b	25 a	31 a
Plant-parasites	(%)	8 a	40 b	26 ab
Pred + Om	100 g soil	83 b	40 a	30 a
Structure index		24 a	49 b	45 b
Detritus		82 b	49 a	59 a
Roots		6 a	37 b	24 ab
Water content		17 b	12 a	13 a
Nitrate-N		67 b	8 a	12 a
pH		6.5 a	7.4 b	7.4 b

Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{zt} = Permanent Bed zone till, PB_{poly} = Hybrid system.

Sixth soil sampling harvest - August 2012, Year 2

There were significant differences, between tillage systems, soil amendment and crops at the harvest sampling in the second year (Table 4-13).

i. Tillage systems

Soil pH, available K, the number of plant-parasitic nematodes and microbial activity (FDA) were all lower in the IT systems relative to the PB_{zt}. However, there was greater sulphate, manganese, and Fe in the IT system relative to the PB_{zt} (Table 4-13). The PB_{poly} system was intermediate for most soil parameters measured.

ii. Soil Amendment

At the final harvest of the zucchini crop there was greater organic C, phosphorus, Cu, Zn and predatory nematodes where additional compost had been applied relative to no additional compost (Table 4-13)

iii. Crop species

Capsicum had greater nitrate-N, K, and Cl relative to the zucchini crop (Table 4-13). Whereas, zucchini had greater Na, microbial activity (FDA) and cellulose degradation (β-glucosidase) relative to the capsicum.

Table 4-13: Significant differences in soil variables due to tillage system in August 2012 when zucchini plants were harvested.

		Tillage system			Compost addition		Crop	
Variable		**IT**	**PB_{zt}**	**PB_{poly}**	**+**	**-**	**Cap**	**Zuc**
Organic C	%				0.85 b	0.77 a		
pH		7.0 a	7.6 b	7.4 b				
Nitrate-N	mg/kg						9.6 b	4.3 a
Phosphorus	mg/kg				180 b	130 a		
Available Potassium	mg/kg	138 a	173 b	145 ab				
Potassium (amm-acet)	Meq/100g						0.42 b	0.35 a
Sodium (amm-acet)	Meq/100g						0.70 a	0.82 b
Sulfate sulphur	mg/kg	14.5 b	8.8 a	12.5 ab				
Chloride	mg/kg						121 b	96 a
Manganese (DTPA)	mg/kg	11.3 b	9.1 a	9.4 a				
Iron (DTPA)	mg/kg	40.5 c	30.3 a	36.8 b				
Copper (DTPA)	mg/kg				1.4 b	1.3 a		
Zinc (DPTA)	mg/kg				1.75 b	1.58 a		
Omnivores & Predators	100 g soil				3 a	4 b		
Omnivores & Predators	(%)				6 a	10 b		
Plant-parasites	(%)	7 a	25 b	19 ab				
Detritus		76 b	56 a	68 b				
Predation					20 b	14 a		
Roots		7 a	25 b	17 ab				
FDA	mg kg^{-1} hr^{-1}	5.9 a	7.5 b	6.2 a			6.0 a	7.1 b
β-glucosidase	µgPNG g^{-1} hr^{-1}						27.9 a	43.5 b

Within each comparison numbers followed by the same letter are not significantly different from one another ($P<0.05$). IT = Intensive tillage, PB_{zt} = Permanent Bed zone till, PB_{poly} = Hybrid system. Cap= Capsicum, Zuc = Zucchini

Discriminant analysis

Following the correlation analysis of the data the variable list was cut down from 59 to 27 uncorrelated variables used in stepwise DA. The initial sampling at the beginning of the experiment had all nutrient, nematode and biochemical measurements made for each sub-plot. This data was used in the correlation analysis and the parameters found correlated in the initial sampling were assumed to remain correlated for subsequent samplings. The subsequent sampling combined samples collected from replicated sub-plots for nutrient analysis.

Using uncorrelated soil parameters which were measured consistently in the fallow, planting and harvest periods in both years, the stepwise discriminant analysis could separate the different tillage treatments based on five soil parameters; Zn, Cu, fungivorous nematodes, β-glucosidase, plant-parasitic nematodes, silt content and chloride (data not shown). Using these five parameters it was possible to separate the three tillage treatments **PB_{poly}**, **PB_{zt}** and IT with some overlap between groupings (Figure 4-3). Using a leave-one-out validation test of the groupings, where the five identified parameters are known for an unknown site, the model was able to correctly assign the **PB_{poly}** 83% of the time incorrectly assigning **PB_{poly}** as IT 17% of the time, correctly assigning **PB_{zt}** 92% of the time incorrectly assigning **PB_{zt}** as IT 8% of the

time and correctly assigning IT 83% of the time incorrectly assigning IT as **PB_{zt}** 8% and **PB_{poly}** 8% of the time (data not shown).

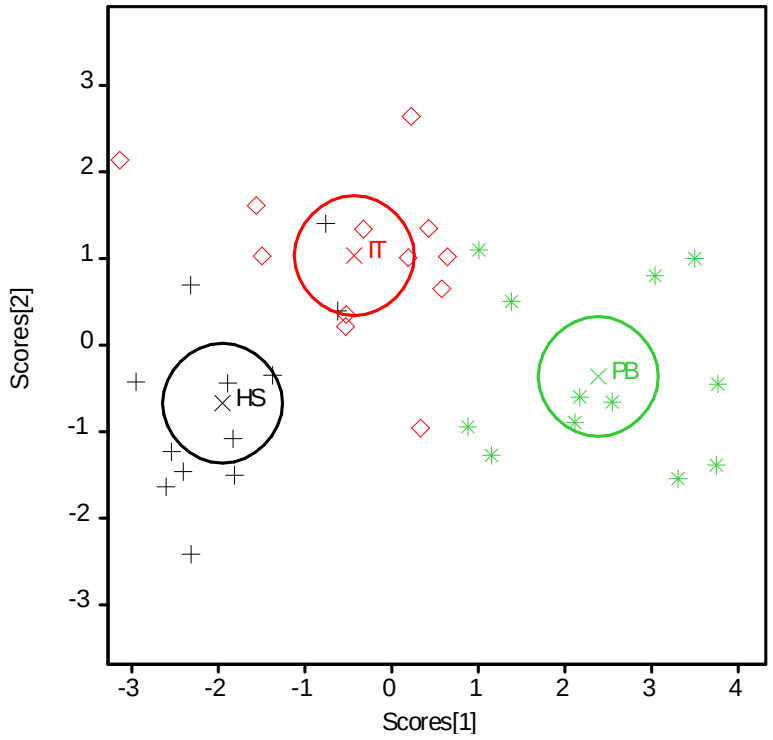


Figure 4-3: Discriminant analysis plot of tillage system differentiation

b. Penetrometer

Penetrometer readings showed an increasing force required with increasing soil depth for all sampling dates at planting and harvest in both 2011 and 2012 (Figure 4-4). There was no significant difference between tillage treatments at planting in June 2011 and 2012. In August 2012 at harvest of the zucchini crop there was a significant interaction between tillage type and plant depth. At harvest in 2011 the PB_{zt} system required considerable force to push the penetrometer for the corresponding depth throughout the profile except for the soil depth of 30-45 cm. The following year in 2012 at the corresponding year there was no significant difference in penetration force required between the different tillage treatments.

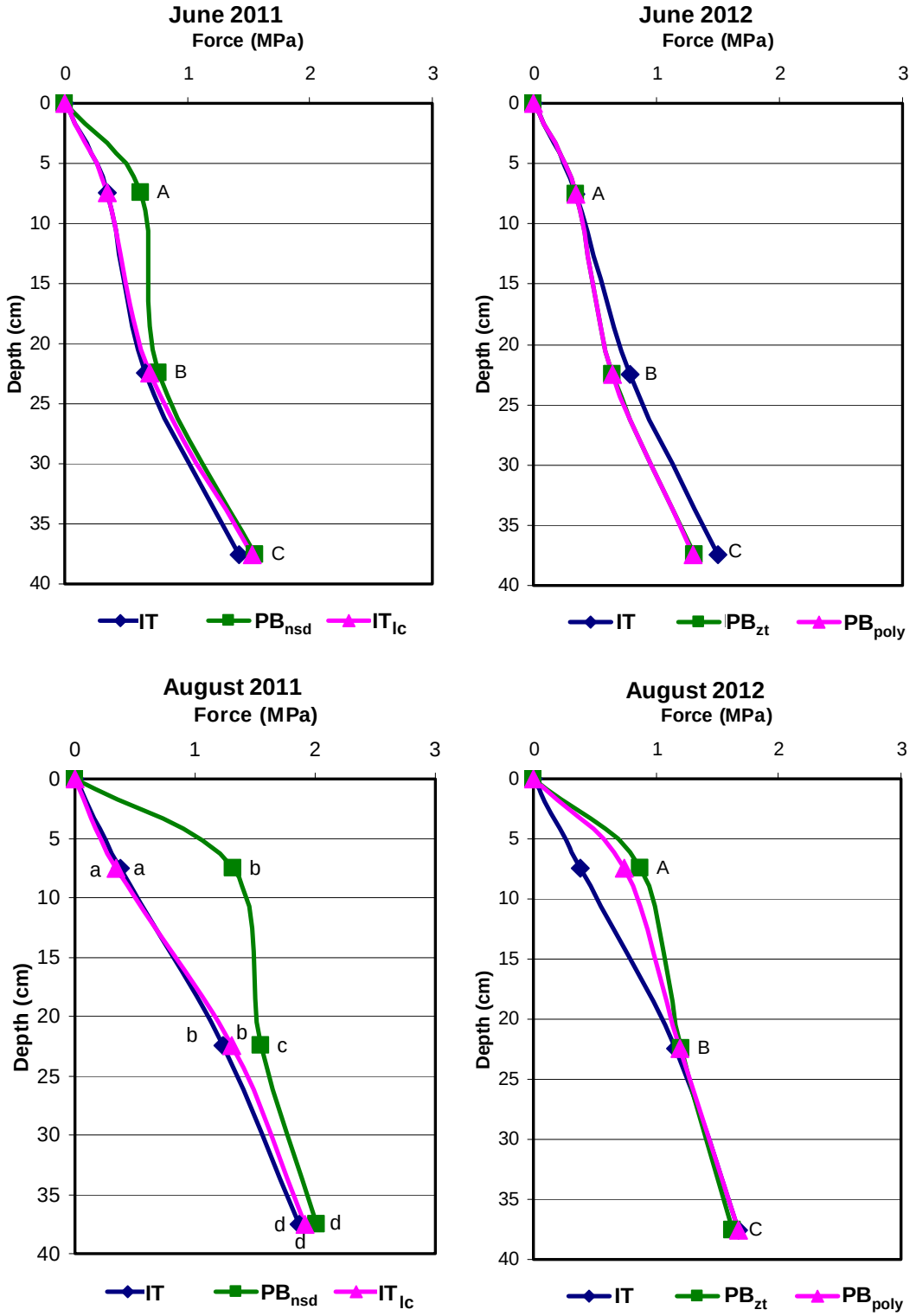


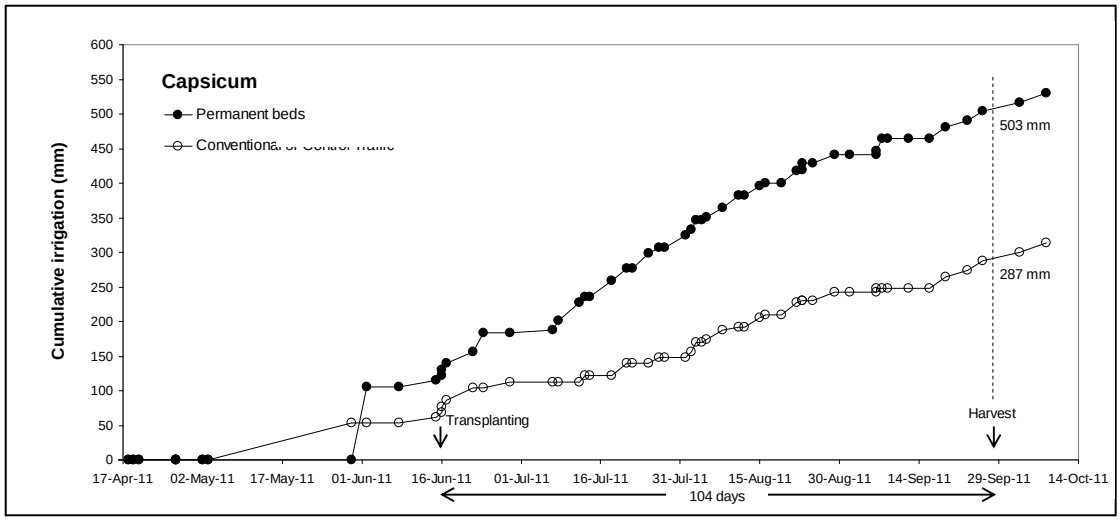
Figure 4-4: Penetrometer resistance down the soil profile averaged over 15 cm increments, under three different tillage systems intensive tillage (IT and IT_{lc} in 2011; IT in 2012), permanent beds (PB_{nsd} in 2011; PB_{zt} in 2012) and a hybrid systems (PB_{poly} in 2012), at planting (June) and harvest (August).

c. Water and nutrient management

Year 1, 2011

In 2011, pre-plant base fertiliser was not used in any of the treatments. The three tillage system treatments received the same amount of nutrients applied through drip. The capsicum received 42 kg N/ha, 6kg P/ha and 79 kg K/ha, whereas the zucchini received a total of 37 kg N/ha, 6kg P/ha and 65 kg K/ha. In the PB_{nsd} systems, irrigation was increased in an attempt to maintain soil moisture conditions at similar levels to those in beds with polyethylene mulch. A total of 314 mm of irrigation was applied to the capsicum growing in the IT and IT_{lc} treatments, while 530 mm was applied to capsicum growing under the PB_{nsd} system (Figure 4-5). Similarly, the zucchinis growing in the IT and IT_{lc} treatments received 243 mm of irrigation, whereas the zucchinis growing in the PB_{nsd} system received 442 mm of irrigation (Figure 4-6).

2011



2012

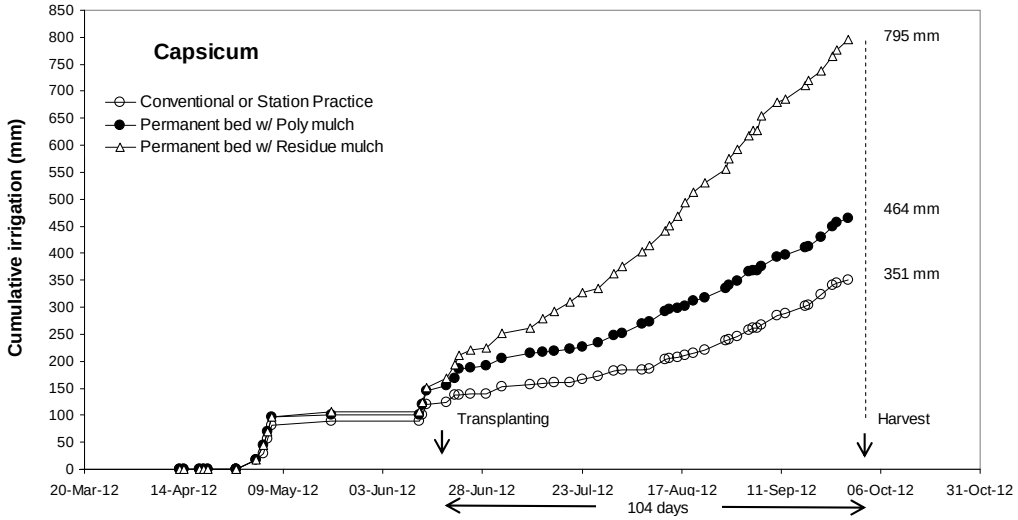
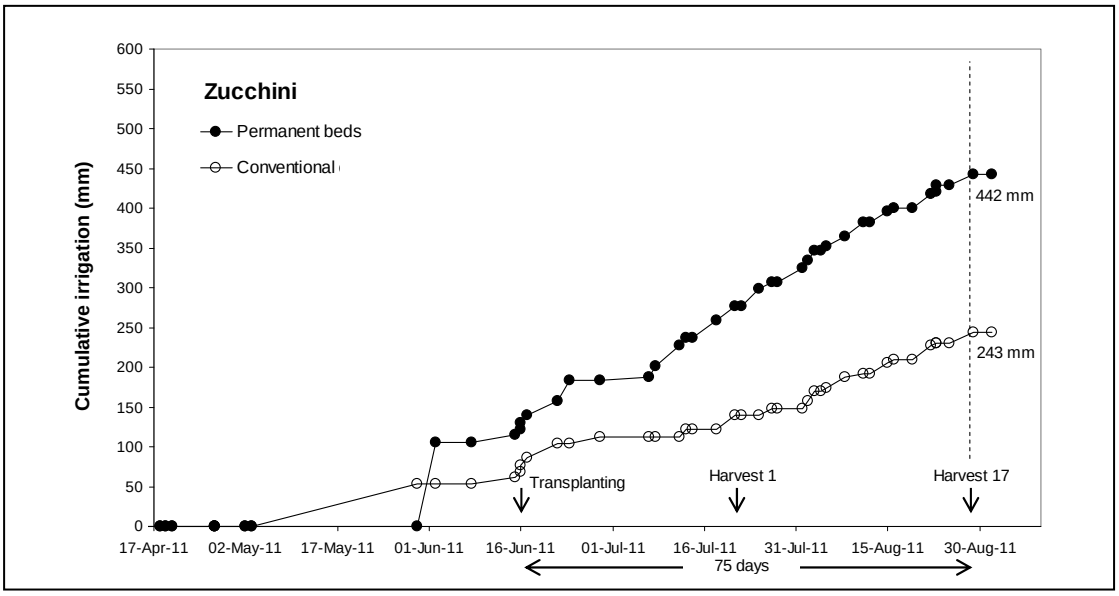


Figure 4-5: Cumulative water delivered through irrigation in "Warlock" capsicum plants grown under different tillage systems, with and without compost addition before planting, in Bowen in 2011 and 2012. The amounts of water delivered were the same in treatments with and without compost within the same tillage system.

2011



2012

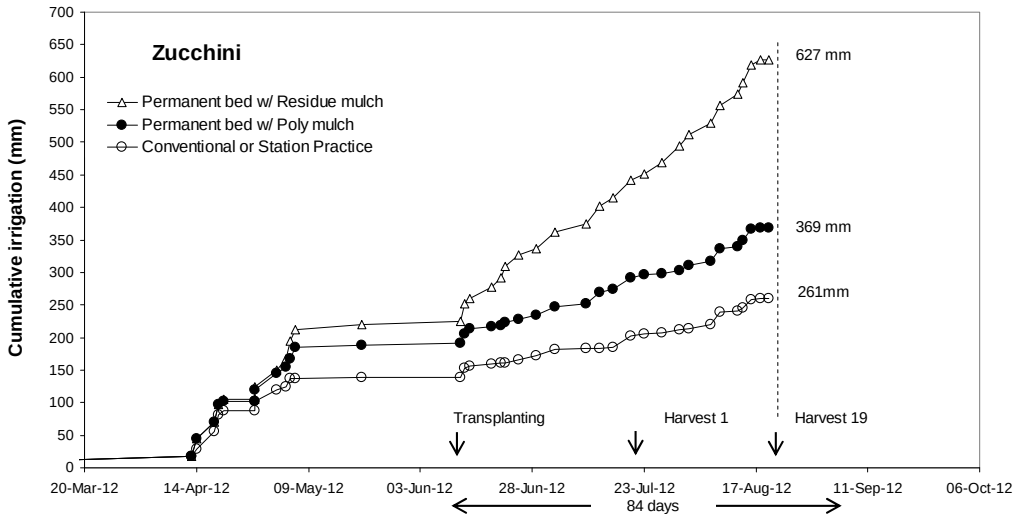


Figure 4-6: Cumulative water delivered through irrigation in "Nitro" zucchini plants grown under different tillage systems, with and without compost addition before planting, in Bowen in 2011 and 2012. The amounts of water delivered were the same in treatments with and without compost within the same tillage system.

Year 2, 2012

In 2012, pre-plant fertiliser was applied to the IT treatment. The three tillage system treatments were managed separately in 2012 and so received differing amounts of water and nutrients. In 2012, the IT capsicum received 132 kg N/ha, 30 kg P/ha and 200 kg K/ha and a total of 351 mm of irrigation (Figure 4-5). Whereas, the PB_{zt} and PB_{poly} received 109 kg N/ha, 6 kg P/ha and 220 kg K/ha and a total of 795 and 464 mm of irrigation respectively (Figure 4-5). Similarly, the zucchinis were managed differently in the different tillage systems. The zucchini in the IT received a total of

108 kg N/ha, 30 kg P/ha and 147 kg K/ha and 261 mm of irrigation (Figure 4-6). The PB_{zt} and PB_{poly} zucchini received 86 kg N/ha, 6 kg P/ha and 168 kg K/ha and 627 and 369 mm of irrigation respectively (Figure 4-6).

The zucchini crop was at risk of water stress, indicated by the tensiometer readings exceeding -30 kPa, in 32% of the readings in the top 40 cm of soil in all treatments. As water became difficult for zucchinis to access in the top 15 cm the crop became reliant on deeper soil moisture, which increased the water tension at 40 and 60 cm (Figure 4-7). Soil water tension in PB_{zt} exceeded the optimal range in the top 15 cm 23% of the time and 5 to 9% of the time in the PB_{poly} and IT. The IT had the greatest soil moisture deficit at 60 cm relative to the PB_{poly} and PB_{zt}. On several occasions, the irrigation wetting front in PB_{zt} moved past the 60 cm tensiometers late in the growing season (Figure 4-7)

The capsicum crop did not appear to be at risk of water stress over the period monitored with the tensiometers. The PB_{zt} and IT treatments exceeded -30 kPa only on one occasion in the top 15 cm and did not exceed -15 at 40 and 60 cm down the soil profile (Figure 4-8). Irrigation frequently moved beyond 40 cm into the 60 cm soil zone suggesting the potential for leaching. PB_{zt} remained consistently wetter at 40 cm due to the greater supply of irrigation water (Figure 4-8).

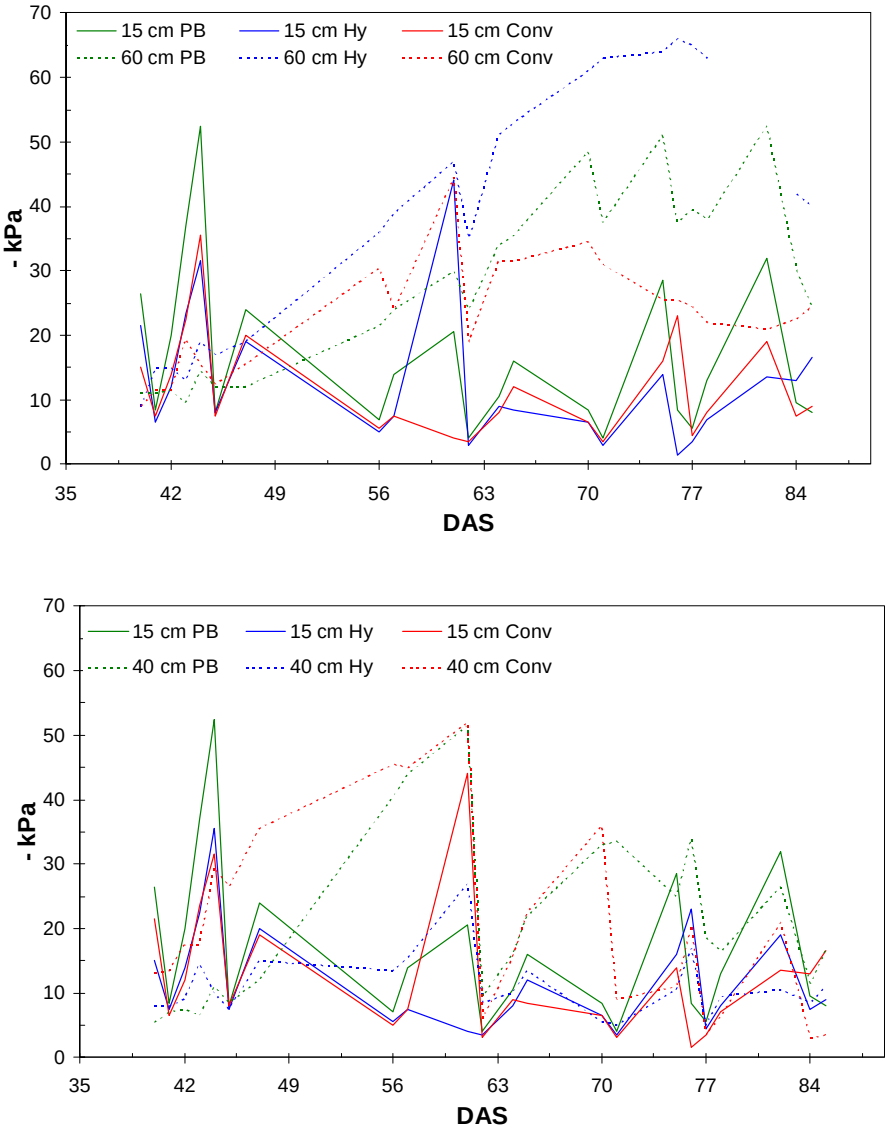


Figure 4-7: Tensiometer readings in zucchini plots in 2012 comparing 15 to 40 cm and 15 to 60 cm down the soil profile in three different tillage systems permanent bed with zone tillage (PB), hybrid system (Hy) and a conventional intensive tillage system (Conv). DAS is days after planting.

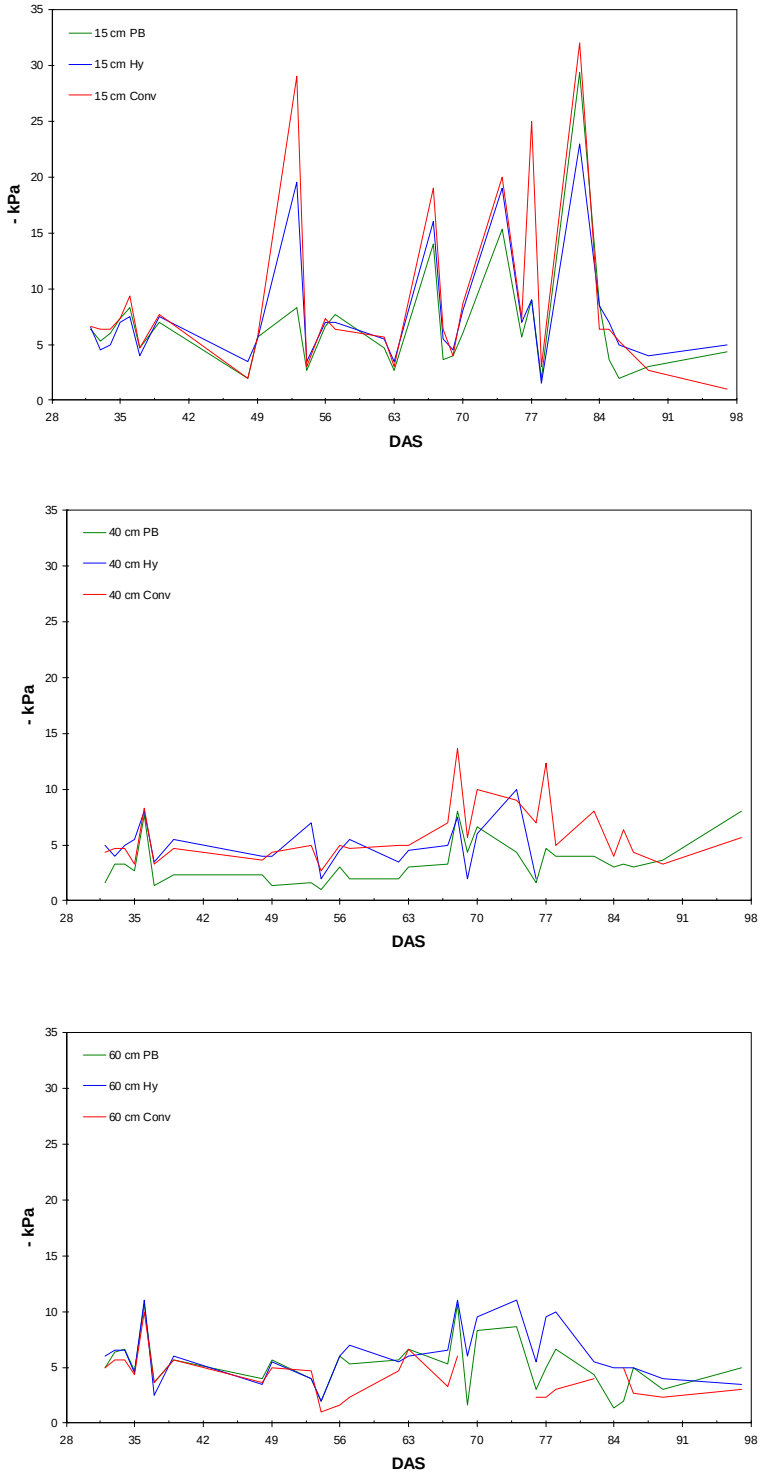


Figure 4-8: Tensiometer readings in capsicum plots in 2012 for 15, 40 and 60 cm down the soil profile comparing three different tillage systems permanent bed with zone tillage (PB), hybrid system (Hy) and a conventional intensive tillage system (Conv). DAS is days after planting.

d. Crop agronomic measurements

Year1, 2011

i. Capsicum

There was a significant decrease in the total and marketable yields of capsicum grown in the PB_{nsd} system relative to IT and the IT_{lc} (Table 4-14). The total marketable yield in the PB_{nsd} system was one third of the other two systems and the total yield was half of the other two systems (Table 4-14). There was a decrease in growth of capsicum in PB_{nsd} the first dry matter sampling after harvest (data not shown) what indicated slow growth early after transplanting. There was also an increase in the number of capsicum fruit showing sunscald damage in the PB_{nsd} relative to the other two systems (Table 4-14). There was no significant difference in marketable yields of capsicum grown with or without compost application (Table 4-14).

Table 4-14: Means for the main effects of fruit yields in "Warlock" capsicum plants grown under three tillage systems, with and without compost addition before planting in Bowen in 2011. A single harvest of fruit with lengths ≥89 mm was carried on plots (30 plants) on 27/09/2011. Small size and rotten fruit were left on the plant.

	Marketable fruit			Unmarketable fruit		Total[f]
	Extra large[a] ($t \cdot ha^{-1}$)	Large[b] ($t \cdot ha^{-1}$)	Total[c] ($t \cdot ha^{-1}$)	Misshap.[d] ($t \cdot ha^{-1}$)	Sunscald[e] ($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)
Tillage						
IT	6.2	11.9 b	18.1 b	5.6	0.6	24.3 b
IT_{lc}	3.7	10.4 b	14.0 b	5.9	0.9	20.8 b
PB_{nsd}	2.3	2.8 a	5.1 a	3.9	1.6	10.6 a
Amendment						
Compost	3.6	8.8	12.4	4.6	1.0	17.9
No compost	4.5	8.0	12.5	5.6	1.1	19.1
Tillage	*0.078*	*0.001*	*<0.001*	*0.280*	*0.234*	*0.007*
Amendment	*0.129*	*0.240*	*0.953*	*0.372*	*0.744*	*0.607*
Tillage × Amend.	*0.208*	*0.301*	*0.360*	*0.516*	*0.694*	*0.798*

IT: Intensive tillage system; IT_{lc}: Intensive Tillage system with less cultivation; PB_{nsd}: Permanent Bed system with no soil disturbance.

[a] Red and green fruit combined with lengths >110 mm

[b] Red and green fruit combined with lengths 90-109 mm

[c] Extra large and large fruit combined

[d] Fruit graded unmarketable because of unaccepted shape and/or they had lengths ≤89 mm

[e] Fruit affected by sun damage

[f] All marketable and unmarketable fruit combined

Plant density: 32,050 plants/ha

ii. Zucchini

Similar to capsicum, there was a significant decrease in the marketable yield of zucchini in the PB_{nsd} system when compared to the IT and IT_{lc} (Table 4-15). However, there was no significant difference in the number of fruit produced per hectare among the three production systems (Table 4-15). The fruit produced from the PB_{nsd} were significantly smaller; approximately 80% of the fruit weight of zucchinis produced in the other two systems. There was also a significant decrease in the yield of unmarketable fruit from the PB_{nsd} (Table 4-15. There was no significant difference in yields as affected by compost

application treatments, and there were no significant interaction between compost application and tillage systems (Table 4-15).

Table 4-15: Means for the main effects of fruit yields in "Nitro" zucchini plants grown under three tillage systems, with and without compost addition before planting in Bowen in 2011. Seventeen harvests were carried from 27/07/11 to 2/09/11 on plots with 40 plants.

	Marketable fruit[a]			Unmarketable fruit[b]		Total[c]	
	(no×1000·ha^{-1})	(t·ha^{-1})	g/fruit	(no×1000·ha^{-1})	(t·ha^{-1})	(t·ha^{-1})	(no×1000·ha^{-1})
Tillage							
IT	140	21.9 b	156 b	6.2	2.8 b	24.7 b	149
IT_{lc}	134	20.0 b	148 b	9.0	2.3 b	22.3 b	143
PB_{nsd}	123	14.8 a	120 a	9.0	1.0 a	15.8 a	129
Amendment							
Compost	133	18.8	141	7.0	1.8	20.7	139
No compost	133	18.9	141	9.1	2.2	21.2	142
Tillage	*0.203*	*0.029*	*0.016*	*0.266*	*0.013*	*0.023*	*0.174*
Amendment	*0.946*	*0.975*	*0.956*	*0.072*	*0.306*	*0.808*	*0.334*
Tillage × Amend.	*0.948*	*0.668*	*0.590*	*0.478*	*0.627*	*0.511*	*0.962*

IT: Intensive tillage system; IT_{lc}: Intensive Tillage system with less cultivation; PB_{nsd}: Permanent Bed system with no soil disturbance.
[a] Includes small and large fruit sizes
[b] Includes oversized and misshapen fruit
[c] All marketable and unmarketable fruit combined
Plant density: 11,375 plants/ha

Year2, 2012

i. Capsicum

There were no significant differences in the yields of capsicum between the three tillage systems (Table 4-16). The greatest production and marketable fruit was approximately 25% greater in the PB_{poly}, relative to the PB_{zt} and IT systems, although this was not significantly different (*P=0.489*). There was double the weight of misshapen fruit in plots that received no compost relative to those that had compost applied (Table 4-16). There was a difference (*P=0.056*) in the weight of extra large fruit, with greater yield in treatments that received compost compared to those that did not receive compost (Table 4-16).

With permanent beds, there was a 35% increase in the amount of total marketable fruit, where plastic mulch had been used relative to using organic mulch on the soil surface (Table 4-17). However, there was also a 30% increase in the number of misshapen fruit where plastic mulch had been used (Table 4-17).

Table 4-16: Means for the main effects of fruit yields in "Warlock" capsicum plants grown under three tillage systems, with and without compost addition before planting in Bowen in 2012. A single harvest of fruit with lengths ≥89 mm was carried on plots (40 plants) on 3/10/2012. Small size and rotten fruit were left on the plant.

	Marketable fruit			Unmarketable fruit		Total[f]
	Extra large[a] ($t \cdot ha^{-1}$)	Large[b] ($t \cdot ha^{-1}$)	Total[c] ($t \cdot ha^{-1}$)	Misshap.[d] ($t \cdot ha^{-1}$)	Sunscald[e] ($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)
Tillage						
IT	4.7	9.0	13.7	2.3	0.37	16.4
PB_{poly}	5.1	11.8	16.9	2.6	0.60	20.1
PB_{zt}	4.0	10.5	14.5	2.1	0.60	17.2
Amendment						
Compost	5.4	10.5	16.0	1.6	0.66	18.2
No compost	3.7	10.4	14.1	3.1	0.38	17.6
Tillage	*0.489*	*0.310*	*0.380*	*0.756*	0.619	*0.437*
Amendment	*0.056*	*0.310*	*0.316*	*0.016*	0.098	*0.644*
Tillage × Amend.	*0.289*	*0.965*	*0.752*	*0.940*	0.105	*0.886*

IT: Intensive tillage system; PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.
[a] Red and green fruit combined with lengths >110 mm
[b] Red and green fruit combined with lengths 90-109 mm
[c] Extra large and large fruit combined
[d] Fruit graded unmarketable because of unaccepted shape and/or they had lengths ≤89 mm
[e] Fruit affected by sun damage
[f] All marketable and unmarketable fruit combined
Plant density: 32,050 plants/ha

Table 4-17: Changes of yield in "Warlock" capsicum plants grown under two permanent bed systems in Bowen in 2012. A single harvest of fruit with lengths ≥89 mm was carried on plots on 3/10/2012. Small size and rotten fruit were left on the plant.

	Marketable fruit			Unmarketable fruit		Total[f]
	Extra large[a] ($t \cdot ha^{-1}$)	Large[b] ($t \cdot ha^{-1}$)	Total[c] ($t \cdot ha^{-1}$)	Misshap.[d] ($t \cdot ha^{-1}$)	Sunscald[e] ($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)
Tillage 2012						
PB_{poly}	4.0	11.8	16.9	2.6	0.6	20.1
PB_{zt}	3.3	9.2	12.5	2.0	0.6	15.1
% Change						
PB_{poly} vs PB_{zt}	21.2	28.3	35.2	30.0	0.0	33.1

PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.
[a] Red and green fruit combined with lengths >110 mm
[b] Red and green fruit combined with lengths 90-109 mm
[c] Extra large and large fruit combined
[d] Fruit graded unmarketable because of unaccepted shape and/or they had lengths ≤89 mm
[e] Fruit affected by sun damage
[f] All marketable and unmarketable fruit combined
Plant density: 32,050 plants/ha

ii. Zucchini

There were no significant differences in the fruit number and total weight of marketable zucchini between the three different tillage treatments (Table 4-18). However, on average, the individual fruit weight was significantly less in the PB_{zt} relative to the IT with the PB_{poly} having intermediate weights (Table 4-18). There was an increase (*P=0.071*) in the number of unmarketable fruit in the IT practice relative to the PB_{poly} and PB_{zt} treatments.

There was no significant difference among the compost treatments (Table 4-18). In 2012, differences in yield between PB_{poly} and PB_{zt} were less than 13% (Table 4-19).

Table 4-18: Means for the main effects of fruit yields in "Nitro" zucchini plants grown under three tillage systems, with and without compost addition before planting in Bowen in 2012. Twenty harvests were carried from 23/07/12 to 5/09/12 on plots with 20 plants.

	Marketable fruit[a]			Unmarketable fruit[b]		Total[c]	
	(no×1000·ha^{-1})	(t·ha^{-1})	g/fruit	(no×1000·ha^{-1})	(t·ha^{-1})	(t·ha^{-1})	(no×1000·ha^{-1})
Tillage							
IT	206	25.2	120 b	30.6	11.8	37.1	237
PB_{poly}	205	23.6	115 ab	11.0	4.0	27.6	216
PB_{zt}	199	22.5	109 a	12.4	4.5	27.1	211
Amendment							
Compost	205	23.8	115	15.5	1.8	20.7	220
No compost	202	23.8	115	20.5	2.2	21.2	223
Tillage	*0.788*	*0.292*	*0.031*	*0.071*	*0.149*	*0.111*	*0.231*
Amendment	*0.709*	*0.949*	*0.914*	*0.443*	*0.285*	*0.235*	*0.904*
Tillage × Amend.	*0.783*	*0.694*	*0.316*	*0.251*	*0.691*	*0.819*	*0.394*

IT: Intensive tillage system; PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.
[a] Includes small and large fruit sizes
[b] Includes oversized and misshapen fruit
[c] All marketable and unmarketable fruit combined
Plant density: 11,375 plants/ha

Table 4-19: Changes of yield in "Nitro" zucchini plants grown under two permanent bed systems in Bowen in 2012.

	Marketable fruit[a]			Unmarketable fruit[b]		Total[c]	
	(no×1000·ha^{-1})	(t·ha^{-1})	g/fruit	(no×1000·ha^{-1})	(t·ha^{-1})	(t·ha^{-1})	(no×1000·ha^{-1})
Tillage							
PB_{poly}	205	23.6	115	11.0	4.0	27.6	216
PB_{zt}	199	22.5	109	12.4	4.5	27.1	211
% Change							
PB_{poly} vs PB_{zt}	-2.9	-4.7	-5.2	12.7	12.5	-1.8	-2.3

PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.
[a] Includes small and large fruit sizes
[b] Includes oversized and misshapen fruit
[c] All marketable and unmarketable fruit combined
Plant density: 11,375 plants/ha

Crop agronomic comparison 2011 to 2012.
In 2012, the IT treatment was managed in a similar way as in 2011. IT in 2012 had pre-plant fertiliser incorporated into the planting beds while this was not done in 2011. However, IT in 2012 led to lower yields than in 2011 (Table 4-20). With capsicum grown under IT in 2012, there was an 18% to 33% decrease in marketable fruit yields and a 35% decrease in the total capsicum fruit harvested with respect to 2011 (Table 4-20). Capsicum fruit quality was better in 2012 than in 2011: there was a 59% decrease in small and misshapen fruit and a decrease of fruit with sunscald (Table 4-20).

Table 4-20: Changes of yield in "Warlock" capsicum plants grown under conventional tillage systems in Bowen between 2011 and 2012. A single harvest of fruit with lengths ≥89 mm was carried on plots on 27/9/2011 and 3/10/2012. Small size and rotten fruit were left on the plant.

	Marketable fruit			Unmarketable fruit		Total[f]
	Extra large[a] ($t \cdot ha^{-1}$)	Large[b] ($t \cdot ha^{-1}$)	Total[c] ($t \cdot ha^{-1}$)	Misshap.[d] ($t \cdot ha^{-1}$)	Sunscald[e] ($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)
Tillage						
IT 2011	6.2	11.9	18.1	5.6	0.6	24.3
IT 2012	5.1	8.1	12.1	2.3	1.3	15.7
% Change IT 2012 vs 11	-17.7	-31.9	-33.1	-58.9	116.7	-35.4

IT: Intensive tillage system
[a] Red and green fruit combined with lengths >110 mm
[b] Red and green fruit combined with lengths 90-109 mm
[c] Extra large and large fruit combined
[d] Fruit graded unmarketable because of unaccepted shape and/or they had lengths ≤89 mm
[e] Fruit affected by sun damage
[f] All marketable and unmarketable fruit combined
Plant density: 32,050 plants/ha

The PB_{nsd} used in 2011 was modified in 2012, by implementing zone tillage, and increasing irrigation frequency and nutrient supply. The modified treatment, PB_{zt}, resulted in a 43% increase in extra large capsicum fruit, 228% increase in large capsicum fruit, 145% increase in total marketable capsicum fruit and a 42% increase in the total capsicum fruit harvested with respect to yields in PB_{nsd} (Table 4-21). Furthermore, with PB_{zt} there was a 49% decrease in the misshapen capsicum fruit and a 62% decrease in the capsicum fruit with sunscald damage with respect to PB_{nsd} (Table 4-21).

The zucchini crop was harvested for a longer period in 2012. However, the zone tillage implemented in PB_{zt} led to yield increases with respect to PB_{nsd} used in 2011 (Table 4-22). Zucchini grown under IT were also managed similarly in 2011 and 2012 with the difference of pre-plant fertiliser that was applied only in 2012. There was a 15% increase in total marketable weight with the IT in 2012 with respect to 2011 (Table 4-23). There were more unmarketable fruit (comprised of overgrown, misshapen or curved fruit) and overall production was greater under the IT in 2012 than in 2011 (Table 4-23).

Table 4-21: Changes of yield in "Warlock" capsicum plants grown under permanent bed systems in Bowen between 2011 and 2012. A single harvest of fruit with lengths ≥89 mm was carried on plots on 27/9/2011 and 3/10/2012. Small size and rotten fruit were left on the plant.

	Marketable fruit			Unmarketable fruit		Total[f]
	Extra large[a] ($t \cdot ha^{-1}$)	Large[b] ($t \cdot ha^{-1}$)	Total[c] ($t \cdot ha^{-1}$)	Misshap.[d] ($t \cdot ha^{-1}$)	Sunscald[e] ($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)
Tillage						
PB_{nsd} (2011)	2.3	2.8	5.1	3.9	1.6	10.6
PB_{zt} (2012)	3.3	9.2	12.5	2.0	0.6	15.1
% Change PB_{zt} vs PB_{nsd}	43.5	228.6	145.1	-48.7	-62.5	42.5

PB_{nsd}: Permanent Bed system with no soil disturbance; PB_{zt}: Permanent bed system with zone till.
[a] Red and green fruit combined with lengths >110 mm
[b] Red and green fruit combined with lengths 90-109 mm
[c] Extra large and large fruit combined
[d] Fruit graded unmarketable because of unaccepted shape and/or they had lengths ≤89 mm
[e] Fruit affected by sun damage
[f] All marketable and unmarketable fruit combined
Plant density: 32,050 plants/ha

Table 4-22: Changes of yield in "Nitro" zucchini plants grown under permanent bed systems in Bowen between 2011 and 2012. In 2011, the permanent bed treatment was modified by implementing zone tillage, and increasing irrigation frequency and nutrient supply.

	Marketable fruit[a]			Unmarketable fruit[b]		Total[c]	
	($no \times 1000 \cdot ha^{-1}$)	($t \cdot ha^{-1}$)	g/fruit	($no \times 1000 \cdot ha^{-1}$)	($t \cdot ha^{-1}$)	($t \cdot ha^{-1}$)	($no \times 1000 \cdot ha^{-1}$)
Tillage							
PB_{nsd} (2011)	123	14.8	120	9.0	1.0	15.8	129
PB_{zt} (2012)	199	22.5	109	12.4	4.5	27.1	211
% Change PB_{zt} vs PB_{nsd}	61.8	52.0	-9.2	37.8	350.0	71.5	63.6

PB_{nsd}: Permanent Bed system with no soil disturbance; PB_{zt}: Permanent bed system with zone till.
[a] Includes small and large fruit sizes
[b] Includes oversized and misshapen fruit
[c] All marketable and unmarketable fruit combined
Plant density: 11,375 plants/ha

Table 4-23: Changes of yield in "Nitro" zucchini plants grown under conventional tillage systems in Bowen between 2011 and 2012. In 2012, the permanent bed treatment was modified by implementing zone tillage, and increasing irrigation frequency and nutrient supply.

	Marketable fruit[a]			Unmarketable fruit[b]		Total[c]	
	(no×1000·ha^{-1})	(t·ha^{-1})	g/fruit	(no×1000·ha^{-1})	(t·ha^{-1})	(t·ha^{-1})	(no×1000·ha^{-1})
Tillage							
IT 2011	140	21.9	156	6.2	2.8	24.7	149
IT 2012	206	25.2	120	30.6	11.8	37.1	237
% Change IT 2012 vs 11	47.1	15.1	-23.1	393.5	321.4	50.2	59.1

IT: Intensive tillage system
[a] Includes small and large fruit sizes
[b] Includes oversized and misshapen fruit
[c] All marketable and unmarketable fruit combined
Plant density: 11,375 plants/ha

The water and nutrient use efficiency suggested that the conventional IT system of production had higher water use efficiency than other tillage systems, but not necessarily higher nutrient use efficiency. In 2011, the PB_{nsd} system with capsicum had approximately a four fold reduction in the N and water use efficiency relative to the IT system (Table 4-24). However, in 2012 the PB_{zt} system with capsicum had greater N use efficiency than the IT, but water use efficiency in the PB_{zt} was still half of that in the IT system (Table 4-24). With increased P applied in the IT in 2012 (from the pre-plant fertiliser), the P use efficiency was particularly low compared to PB_{zt} PB_{poly} treatments (Table 4-24).

Zucchini grown under IT systems had high water use efficiencies than permanent bed systems with only organic mulch, both in 2011 and 2012 (Table 4-25). The water use efficiency with either the PB_{nsd} or PB_{zt} was approximately one third of the IT systems used in 2011 and 2012. In 2012, the N use efficiency was similar across tillage systems. As with capsicums, there was a low P use efficiency with zucchini under the IT system with respect to zucchini under PB_{zt} and PB_{poly}. The addition of polyethylene mulch over a permanent bed (PB_{poly}) almost doubled the water use efficiency of permanent beds that had only organic mulch (PB_{zt}) (Table 4-25).

Table 4-24: Total N-P-K nutrients and total water delivered, and nutrient and water use efficiencies for marketable yield in "Warlock" capsicum plants grown under different tillage systems in Bowen in 2011 and 2012.

	Total N - P - K nutrients supplied[a] ($kg \cdot ha^{-1}$)	Nutrient use efficiency for Marketable fruit[b] N ($kg\text{-}fruit \cdot kg\text{-}N^{-1}$)	P ($kg\text{-}fruit \cdot kg\text{-}P^{-1}$)	K ($kg\text{-}fruit \cdot kg\text{-}K^{-1}$)	Total water (mm)	Water use efficiency of Marketable fruit[c] ($kg\text{-}fruit \cdot m^{-3}$)
Tillage 2011						
IT	42 - 6 - 79	431	3088	229	314	5.8
IT_{lc}	42 - 6 - 79	333	2388	177	314	4.5
PB_{nsd}	42 - 6 - 79	121	870	65	530	1.0
Tillage 2012						
IT	132 - 30 - 200	104	457	69	351	3.9
PB_{poly}	109 - 6 - 220	155	2864	77	464	3.6
PB_{zt}	109 - 6 - 220	133	2458	66	795	1.8

IT: Intensive tillage system; IT_{lc}: Intensive Tillage system with less cultivation; PB_{nsd}: Permanent Bed system with no soil disturbance; PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.

[a] P and K listed in the table are expressed as weights of elements. Fertilisers included soluble grades of 20.9-8.6-16.2 (Flowfeed CO3), potassium nitrate (13.0-0-38.3), and calcium nitrate (15.5-0-19.0), delivered through irrigation. In 2012 dry pre-plant fertiliser CK55 (13.5-15.0-12.5) was incorporated into the beds of the IT treatment only. In 2012, fertilisation applications through fertigation were increased for crops under permanent systems.

[b] Nutrient use efficiency calculated as marketable yield per kg of nutrient applied. Marketable fruit included red and green fruit of extra large and large fruit sizes combined.

[c] Water use efficiency calculated as marketable yield per cubic meter of water applied. Irrigation in mm × 10,000 = $L \cdot ha^{-1}$ = 1/1000 $m^3 \cdot ha^{-1}$

Table 4-25. Total N-P-K nutrients and total water delivered, and nutrient and water use efficiencies for marketable yield in "Nitro" zucchini plants grown under different tillage systems in Bowen in 2011 and 2012.

	Total N - P - K nutrients supplied[a] ($kg \cdot ha^{-1}$)	Nutrient use efficiency for Marketable fruit[b] N ($kg\text{-}fruit \cdot kg\text{-}N^{-1}$)	P ($kg\text{-}fruit \cdot kg\text{-}P^{-1}$)	K ($kg\text{-}fruit \cdot kg\text{-}K^{-1}$)	Total water (mm)	Water use efficiency of Marketable fruit[c] ($kg\text{-}fruit \cdot m^{-3}$)
Tillage 2011						
IT	38 - 6 - 65	587	3736	337	243	9.0
IT_{lc}	38 - 6 - 65	536	3412	307	243	8.2
PB_{nsd}	38 - 6 - 65	396	2525	227	442	3.3
Tillage 2012						
IT	108 - 30 - 147	233	840	171	261	9.7
PB_{poly}	86 - 6 - 168	274	3933	140	369	6.4
PB_{zt}	86 - 6 - 168	262	3750	134	627	3.6

IT: Intensive tillage system; IT_{lc}: Intensive Tillage system with less cultivation; PB_{nsd}: Permanent Bed system with no soil disturbance; PB_{poly}: Hybrid system; PB_{zt}: Permanent bed system with zone till.

[a] N-P-K fertilisers included soluble grades of 20.9-8.6-16.2 (Flowfeed CO3), potassium nitrate (13.0-0-38.3), and calcium nitrate (15.5-0-19.0), delivered through irrigation. In 2012 dry pre-plant fertiliser CK55 (13.5-15.0-12.5) was incorporated into the beds of the IT treatment only. In 2012, fertilisation applications through fertigation were increased for crops under permanent systems.

[b] Nutrient use efficiency calculated as marketable yield per kg of nutrient applied.

[c] Water use efficiency calculated as marketable yield per cubic meter of water applied. Irrigation in mm × 10,000 = $L \cdot ha^{-1}$ = 1/1000 $m^3 \cdot ha^{-1}$

4.5. Discussion

The results from the two years of trials with two crops capsicum and zucchini suggested that permanent bed systems could be successfully implelemted into vegetable production, but required different agronomic management to conventional intensive tillage and plasticulture. In 2011, the first year of the experiment, the PB_{nsd} system led to low marketable yields, with a 70% reduction for capsicum and 30% reduction for zucchini, relative to the IT system. The identification of crop production constraints in the permanent bed treatment of 2011 was used to decide and implement changes in crop management in subsequent zucchini and capsicum crops under permanent beds in 2012. For this purpose, all beds in the trial had to be reformed at the end of 2011. A key modification implemented in 2012 was zone tillage in permanent bed systems, which was used in treatments PB_{zt} and PB_{poly}. This minimal vertical tillage affects less than 10% of the area compared to an intensive tillage scenario for capsicums planted in two rows per bed. The soil disturbance impact per hectare would be even smaller with zucchini as they are planted in a single row per bed.

The polyethylene mulch on permanent beds in PB_{poly} was used to reduce water use, better manage weeds, and increase soil temperature during the cool season. Conventional polyethylene mulch laying equipment performed well over beds with sorghum residue for the purpose of the trial; although simple modifications to this equipment are needed for use on a commercial farm. Biodegradable mulch, probably thicker than what is commercially used, would be a better option for a PB_{poly} system because removal and disposal of the mulch would be unnecessary.

Increased nutrient supply and irrigation water were also used with treatments PB_{zt} and PB_{poly} in 2012. The use of tensiometers or other soil moisture measurement devices would be critical for scheduling irrigation with permanent beds, particularly if polyethylene or biodegradable mulch was not used.

Much of the improvement in the PB_{zt} and PB_{poly} systems could be attributed to overcoming compaction using zone tillage. The penetrometer results at the time of fruit harvest in 2011 showed a significant interaction between tillage systems and depth in the soil profile, with PB_{nsd} being significantly more compact than IT or IT_{lc} at the same soil depth. The zone tillage equipment loosened the soil sufficiently to allow the seedlings to become effectively established (very few replants of seedlings were needed) and reduce impediments to root growth. At the time of crop harvest in 2012, there was no difference in penetration force into the soil with respect to earlier measurements in the crop season. Although the yield penalties from the 2011 crops would be unacceptable in commercial production, the results highlighted compaction as a soil constraint and allowed modifications to be made to the system resulting in greater productivity in subsequent crops in the permanent bed systems. The findings and outcomes of these first two crop seasons provide important information for vegetable growers contemplating conversion from conventional systems to permanent beds systems where soil compaction issues could greatly reduce yields.

The combination of these crop management changes, zone tillage, increased nutrient and water supply, appeared to overcome the production constraints of 2011. Moreover, there was a 145% increase in the total yield for capsicum grown in the permanent bed systems from 2011 to 2012, resulting in yields that were equivalent to

capsicums grown under IT. The changes in permanent bed treatments also led to greater marketable yields in zucchini (a 50% increase with PB_{zt} in 2012 with respect to PB_{nsd} in 2011) and which were equivalent to yields of zucchini grown under IT.

In the first year of the experiment in 2011, the PB_{nsd} system was less efficient in the use of water and nutrients for marketable production of either capsicum or zucchini. A system without impermeable mulch, such as polyethylene, will require greater volumes of irrigation water. Increase of irrigation water volumes in PB_{zt} in 2012 might have contributed to the increased capsicum and zucchini yields with respect to yields in 2011; although with the use of organic mulch, water use efficiency could be further improved by more frequent, shorter irrigation events.

The nutrient use efficiencies in the PB_{nsd} and PB_{poly} systems were greater than in the IT system mostly due to the use of a pre-plant fertiliser application in the IT system. The use of pre-plant fertiliser is standard practice for vegetable production, but may not be used as efficiently as with nutrients supplied via fertigation. Furthermore, many pre-plant fertilisers may also contribute to increasing P accumulation in the soil, if applied every year.

Irrigation management in the PB_{zt} and PB_{poly} were more closely monitored in 2012 relative to 2011 using soil moisture monitoring equipment to schedule irrigation. The PB_{zt} system having organic mulch on beds had the lowest water use efficacy relative to the IT system. Under the organic mulch there was a greater potential for soil moisture loss through evaporation relative to plastic mulch systems. The water use efficiency in the PB_{zt} remained about one third of the IT, and required more frequent irrigation, using more than double the amount of water. This would mean the use and adoption of PB_{zt} system with organic mulch could be limited in regions or years with low water availability for irrigation. However, the PB_{poly} system which retains many of the features of the PB_{zt} system but with polyethylene mulch could be used to improve water use efficiency. Biodegradable plastic mulch could still make permanent bed systems with minimum tillage a viable option for regions or years with low water availability for irrigation.

The application of compost in the fallow period had a significant effect on reducing the number of small and misshapen capsicum fruit in 2012. However, there were no differences in yields of zucchini with the addition of compost. Corresponding to the compost applications was also a significant increase in the organic C levels for the same period at harvest in 2012. The compost addition and the increase in organic C appeared to increase the capsicums tolerance to environmental stress resulting in fewer unmarketable fruit and more extra large fruit relative to soils not receiving compost. The applied compost potentially contributed an additional 915 kg/ha of C, 90 kg/ha of N and 122 kg/ha of P. There was an increase in the Cu, Zn and P levels in the soil, as well as an increase in the proportion of nematodes involved in predation of other soil nematodes. If compost is added to the system every year, it could be anticipated that there will be benefits from an increase in organic C, increase in the proportion of predatory organisms, and an improvement of conditions that sustain plant growth and yield. Nutrients in the soils should be monitored as the continual use of compost could potentially increase the levels of P and trace elements like Cu and Zn in soil. If compost is added to the soil there would be no need to add additional P in the fertiliser program. It may be possible to make more efficient use

of the compost by applying it closer to the planting of vegetables, such as within the zonal tillage just prior to this operation, instead of applying the compost as broadcast on top of the beds before the fallow period.

At the commencement of the trial, the site could be described as having degraded soil health, as soil organic C, soil biochemical measurements, and nematode community indices were all relatively low. The organic C of the soil was regarded as low, with an overall average of 0.79%. This is typical for soil in the dry tropics vegetable production area, as most areas undergo intense cultivation prior to planting vegetable crops and the fallow periods, sometime from October to March, are dominated by low growing grasses with low biomass. While the depletion of the soil allows a study to determine how tillage systems may increase soil physical, chemical and biological parameters, it also presents challenges due to greater constraints to vegetable production when the system is altered. This was evident when plots were first converted into the permanent bed system in 2011 as the soil became compacted in the top 15 cm. Normally tillage and use of plastic mulch would compensate for poor soil structural stability; however, this was not possible in the minimum tillage, permanent bed system. The compaction had the effect of restricting seedling growth, and the plants in PB_{nsd} were not able to catch up in growth with those in IT, thus subsequently produced lower yields. This presents a challenge for growers in trying to increase soil organic C to improve structure but also remain profitable in vegetable production. The use of high biomass fallow crops such as forage sorghum with permanent beds and zone tillage systems may allow profitable vegetable production while increasing soil organic C that, with time, will provide improved soil health. However, this may mean the fallow crop needs to be managed to ensure greatest biomass production to enhance organic matter inputs into the soil.

The identification of production constraints was the first step to improving soil and crop management. The development of zone tillage equipment allowed compaction to be overcome with minimal disturbance of the soil. Another important component of managing the compacted surface soil is to ensure soil water remains adequate so that plants can take up water. Polyethylene or biodegradable mulch will also reduce compaction by reducing drying out of the soil surface. The application of compost and organic mulch to the soil surface could potentially reduce compaction on the soil surface and encourage soil fauna as ecosystem engineers, such as earthworms and large insects, to rebuild soil structure, but this has not been evident so far in the trial.

The permanent bed systems appeared to slow the biological activity in the soil and increase the development of the soil food web structure. The permanent bed system had a greater number of omnivorous nematodes which increased the nematode structure index. This suggested that feed back loops of soil organisms were being developed. There was also a significantly reduced number of nematode bacterivores in the permanent bed systems, which suggested less readily available nutrients and resulted in a lower enrichment index. The early indication of soil parameters from the permanent bed system suggested there was a change in soil biology developing, with a greater potential for nutrient recycling and complex food webs with predation, top down predators, contributing to regulation of soil microorganisms. There also appeared to be crop species related differences in soil microbial parameters, with greater microbial activity and cellulolytic organisms under the zucchini relative to the capsicum. Some of these differences may be attributed to the different nutrient use

efficiency under the two crops as the capsicum appeared to be less efficient at utilising water and nutrients, which led to an increase in soil nitrate in 2012 under the capsicum relative to the zucchini.

The potential for weed infestations in the production systems using organic mulch is much greater than when plastic mulch is used. This is particularly relevant if rainfall events occur during the "normally" dry season of production in North Queensland. Therefore, if the organic mulch system were to be adopted by vegetable growers they would need to consider the likelihood of rainfall and how they may manage weeds that may germinate following the rainfall. It is important to consider the withholding period to harvest for several herbicides that could otherwise be used during the cropping period in minimum tillage systems. The critical area to manage will be those where zone tillage is practiced and little or no sorghum mulch covers the soil. Rapidly growing crops with large leaves that shade the beds (such as zucchini) will perform better with respect to weed management. Equipment may be required allowing herbicides to be applied with shielded sprays close to the crop. Close management of irrigation is necessary in the systems with organic mulch to prevent wetting the soil surface, as this will stimulate weed germination.

4.6. Conclusion

In the Dry Tropics of North Queensland, permanent bed systems with minimum tillage and organic mulch, such as PB_{zt} and PB_{poly} evaluated in these trials, have the potential to produce equivalent yields to conventional vegetable production systems that use intensive tillage and polyethylene mulch. To achieve yields under permanent beds that are comparable to conventional tillage systems it was necessary to overcome soil constraints and adapt agronomic practices that would favour plant growth without implementing excessive soil disturbance. Water, nutrient and weed management are quite different with permanent bed systems and recommendations have to be developed for specific crops. Soils that have become degraded create a greater challenge for permanent bed minimum tillage systems, as loss of soil structure due to reduced organic carbon levels restricts crop yields if not managed, but to rebuild soil organic C levels requires minimal soil disturbance and continual organic matter inputs. The use of zone tillage equipment, such as a wavy disc cultivator, goes someway to overcoming the parody. Zone tillage in double rows as used with capsicums in 2012 created a vertical till in less than 10% of the area compared to intensive tillage scenarios. The benefits from increased organic C in soils, as created with the addition of compost, appear to improve growing conditions of capsicum plants, which can then lead to increased yields of high quality fruit while reducing production of unmarketable fruit. This could also suggest that capsicum plants grown in soils with greater organic C were more tolerant of environmental stress than soils with low organic C. The permanent bed system with organic mulch and zone tillage was less efficient in water use than systems using polyethylene mulch, but appears to be as efficient in the utilisation of nutrients. If irrigation water was to be restricted, a permanent bed system with polyethylene mulch or better, biodegradable mulch, will greatly improve water use efficiency. At this stage of the trial, there is some indication that the minimum tillage can lead to improved soil health, as greater microbial activity could be measured under the permanent bed systems. The addition of compost contributed to increased soil organic C and increased the number of

predatory organisms, suggesting more a complex soil food web than with intensive tillage systems, and with the potential to reduce the activity of plant pathogens in soil.

4.7. References

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5. Pictorial summary of minimum tillage vegetable production

5.1. Permanent beds in vegetables in north Qld

Photo 1. Permanent bed systems with zucchini plants in a commercial farm at Giru, Queensland. Zucchini has the largest area under this type of tillage system in North Queensland. Sorghum is the summer cover crop and it is used to form the plant residue mulch over the beds. Farming uses GPS assistance and crops are established using no-till seeding equipment. On average, beds are reformed every five years, and the production system has been used for about 12 years. Organic carbon levels in the top 10-cm of the soil profile range from 1.5 to 2.0 %.

5.2. Field Trial at Bowen, Qld

A detailed description of systems is included in the written section North Queensland Field Trial. Tillage systems were evaluated on zucchini and capsicum, with and without an annual addition of compost at the DAFF Bowen Research station in 2011 and 2012.

Photo 2. In 2011, intensive tillage treatments included plasticulture and two levels of tillage intensity (IT and IT_{lc}; both same appearance as on the left of the image) and a treatment of a permanent bed system with no soil disturbance and sorghum residue as bed mulch (PB_{nsd}; right).

Photo 3. In 2012, there was only one intensive tillage treatment (IT; top) which included plasticulture and two permanent bed treatments. Both permanent bed treatments had minimum tillage (zone till) but one of them had a polyethylene film laid on top of the sorghum residue as a mulch (PB_{zt}; center, and PB_{poly}; bottom). In 2013, the use of polyethylene on permanent beds has been replaced with a biodegradable mulch.

5.3. Summer cover crop

In the first year, beds were formed with GPS assistance. Drip tubing was placed about 7 cm below the bed surface. Pre-plant fertiliser was incorporated in beds for the first cover crop. Sorghum "Jumbo" was used as a cover crop in the trial at Bowen. There are several other cover crops that could be used and that were not tested in this project.

Photo 4. Sorghum in permanent beds was planted in double rows, close to the edges of the planting bed. Sorghum planted in permanent beds in November 2010 and 2011 were not irrigated or fertigated during the summer (left). Planting density and plant establishment were improved (spacing 5 cm) in years 2011 and 2012 (right). High plant density will produce thinner stalks, a benefit in permanent bed systems where a biodegradable or polyethylene mulch film is laid on top of sorghum residue.

Photo 5. Good but minimal maintenance of the summer cover crop is important for producing biomass that will become the residue bed mulch over permanent beds. Thick residue mulch on planting beds will help with weed control, soil compaction and, with time, add organic matter to the top soil. Sorghum was planted again in November 2012 after the capsicum and zucchini crops were terminated. There were few and small rainfall events until early January 2013. This limitation was overcome in permanent beds because two irrigation and one fertigation event (20 kg/ha of N applied as urea) could be provided through the existing subsurface drip tubing (taller group of plants on the left in each frame). Sorghum plants in the conventional tillage system did not receive the additional water and nutrients as this would be more difficult to implement (shorter group of plants on the right in each frame).

Photo 6. Sorghum is slashed and mulched during the summer 2012-13.

Photo 7. Rapid regrowth of sorghum after slashing during the 2012-13 summer season (left) and residue mulch over permanent beds (right). In March, the regrowth after slashing was sprayed with herbicide (e.g. glyphosate and glufosinate-ammonium). This plant material created the residue mulch over permanent beds. Additional herbicide spray may be required when conditions are favourable for sorghum regrowth.

5.4. Compost

Photo 8. Tillage treatments in the trial at Bowen were tested with and without an annual application of compost. Compost was made up of by products of the sugar cane industry and included a mix of mill mud and bagasse. Compost sources were from Proserpine in 2011 and 2012, and from Giru in 2013 (right). For the 2011 and 2012 trial crop seasons, compost was applied (15 t/ha) on top of the beds before planting the sorghum in the previous November. For the 2013 cropping season, 15 t/ha of compost were applied either in bands and incorporated with zone tillage before transplanting in permanent beds (left) or, when forming the beds in the intensive tillage treatment.

5.5. Zone till in permanent beds

Photo 9. Wavy disc coulters 55-cm diameter were used in pairs in 2012 and 2013 to create zone tillage of two 8-cm bands on the two permanent beds (PB_{zt} and PB_{poly}) in the trial at Bowen (top and centre). In 2013, the zone tillage was also used over the bands where compost had been applied (bottom). Soil moisture and tractor speed were variables to consider when the equipment was set up for work before transplanting. Similar equipment was used overseas for zone till permanent beds in vegetables. The discs were borrowed from prototype equipment designed for sugar cane by BSES and Hodge Industries, Mackay.


Photo 10. A conical roller was used to flatten soil crumbs during zone tillage before laying the biodegradable film mulch in 2013. A better option could be the use of a crumble roller or rolling basket as in Photo 12.



Photo 11. Recently, some growers have also been experimenting zone tillage in a zucchini farm using an implement conformed of a pair of vertical cutting discs and two inverted knives that horizontally cut the soil underneath the buried drip tubing (left and centre). The wavy disc coulters used in the Bowen trial have been tried as well (right).


Photo 12. A commercial zone till equipment from overseas designed for growing vegetable crops on permanent beds (left). For each zone till, this model includes a cutting disc at the front (right), followed by deep tillage shank, two wavy disc coulters (or mound discs) and a rolling basket. Source: Vegetable Farmers and their Sustainable Tillage Practices [DVD]. V. Grubinger. 2007. University of Vermont Extension (http://www.youtube.com/watch?v=hdnr7ymlpKs).

5.6. Film mulch over permanent beds

Polyethylene (2012) and biodegradable mulch (2013) were laid on beds with sorghum residue. A pass of a roller pulled behind zone tillage equipment may be needed to flatten stems of plant residues and to break large soil crumbles. Optimal soil moisture conditions are required. A modified conventional plastic mulch film bed laying implement was used in the trial. Modifications and correct setup should aim to avoid clogging of dry plant material and sorghum roots and effectively divert soil to hold the film. The front tynes in the laying implement were aligned with the row of sorghum stubble, which was good for removing plant material that could damage the film. However, the tines may clog with sorghum stubble, which occurred in 2013 with a large sorghum root mass and high soil moisture.

Photo 13. Polyethylene mulch laid on permanent beds with zone tillage before planting in the trial at Bowen in 2012 (Treatment PB_{poly}) and biodegradable mulch in 2013.

Photo 14. There was less sorghum residue over permanent beds in 2012 and this made easier to lay the polyethylene mulch.

Photo 15. In 2013, the larger sorghum plants and four slashes during the summer led to thicker mulch over the permanent beds, but this stubble made the laying of biodegradable mulch more challenging (left). A possible addition of two outer flat cutting discs or wavy disc coulters that could cut through the sorghum stubble before laying a film mulch (right).

Photo 16. Beds ready for transplanting in 2013. The Permanent bed with sorghum residue and minimum tillage (top), and the same practices but with the beds covered with a biodegradable mulch (centre) to be tested in 2013. In 2012 polyethylene film mulch was used in one of the permanent bed treatments, and the film was difficult to remove at the end of the cropping season. The biodegradable mulch tested after this project is based on a corn starch material (Mater-Bi) and when degraded by microorganisms would not leave toxic residues or pieces of film that may build up in soils. Intensive tillage beds covered with polyethylene film mulch (bottom).

5.7. Transplanting

Photo 17. Transplanting zucchini on permanent beds with only sorghum residue as mulch (left), and on permanent beds with a biodegradable film (30 and 25 microns thickness) in 2013. A conventional water wheel planter with increased water flow supplied to seedlings was effective for transplanting. For commercial applications suggested modifications could include a larger water tank. A fertiliser N-P-K: 21-9-16 was used to prepare a starter transplanting solution with 150 ppm of N.

Photo 18. Zucchini transplanted in mid June 2012: on permanent beds with only sorghum residue as mulch (left), and on permanent beds with a polyethylene film (middle), and on polyethylene mulched beds of intensive tillage system (right).

Photo 19. Another possibility for transplanting in permanent beds with plant residues and no film is a no-till planter, such as this Canadian RJ Equipment plug planter that has been used by a grower in Bowen.

5.8. Crops in 2011, when no soil disturbance was practiced on permanent beds

Capsicum

Permanent bed

Intensive tillage

Zucchini

Permanent bed

Intensive tillage

Photo 20. Capsicum and zucchini plants grown with a permanent bed system with no soil disturbance (treatment PB_{nsd}) and with intensive tillage (IT) in the field trial at Bowen in 2011. Harvest for zucchini included 17 picks from 27 July to 29 Aug and, for capsicum, a single pick of fruits on 27 Sept.

Photo 21. Zucchini "Nitro" and capsicum "Warlock" on permanent beds with sorghum residue bed mulch (A) and on conventional plasticulture systems with intensive tillage in the first season (B) in 2011 in the trial at Bowen, Qld.

Photo 22. Delayed growth of capsicum and zucchini plants when they were planted in permanent beds with a conventional planter and with no zone tillage (left) compared to plants grown in beds with intensive tillage and plasticulture. August 2011.

Photo 23. Capsicum plants in the trial at Bowen in 2011 at 50 days after transplanting (left image) and 70 days after transplanting (right image). Reduced growth of capsicum plants grown with the permanent bed system with no soil disturbance (treatment PB_{nsd}, on the right in each photo) and compared to plants grown with conventional intensive tillage (treatment IT; on the left in each photo).

5.9. Crops in 2012 after implementing changes in practices on permanent bed systems

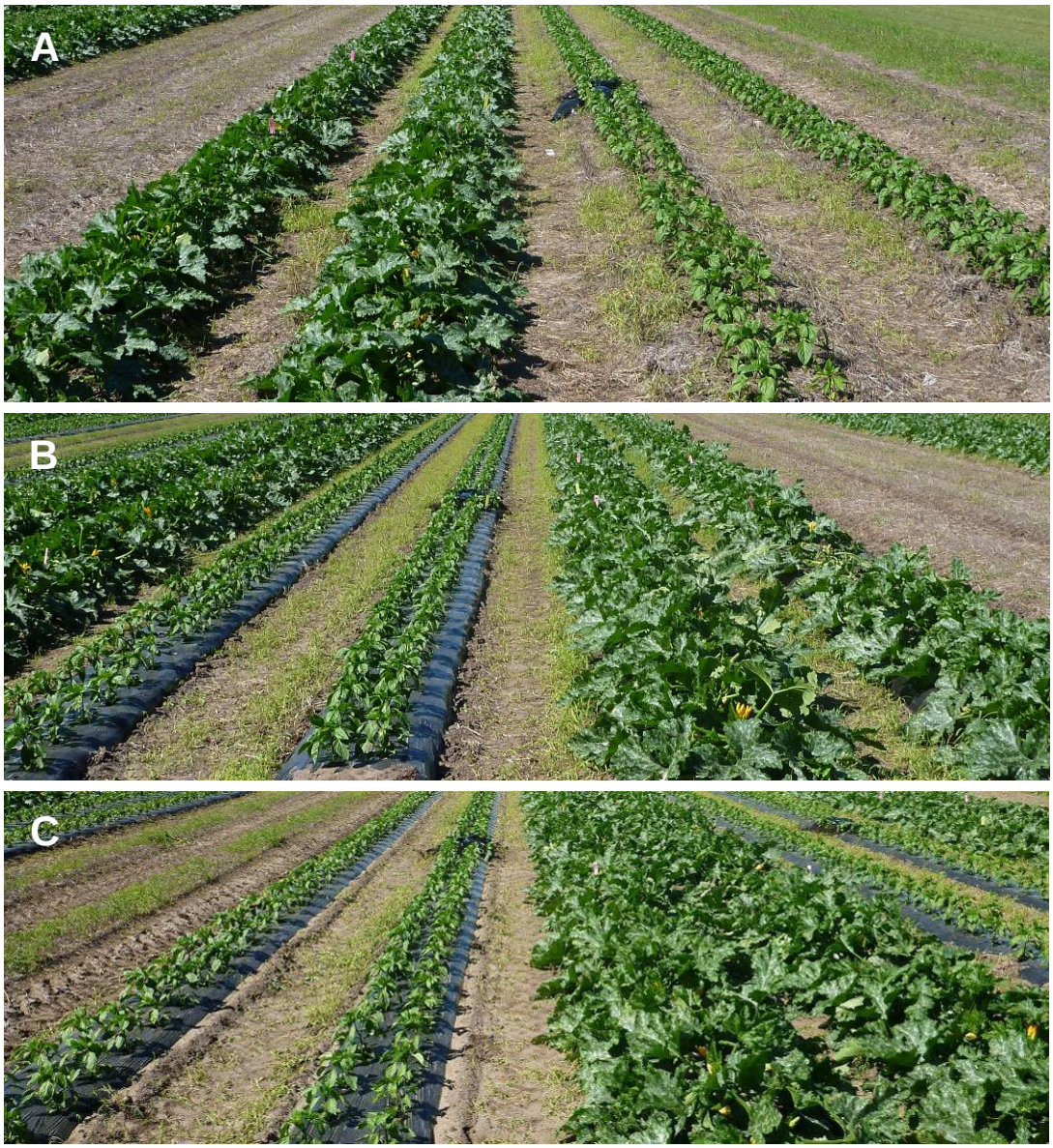


Photo 24. Zucchini "Nitro" and capsicum "Warlock" on permanent beds with zone tillage and sorghum residue bed mulch (A), on permanent beds with zone tillage and polyethylene film mulch (B), and on a conventional plasticulture system with intensive tillage (C) in the second crop season in 2012 (15 July) in the trial at Bowen, Qld. Inter rows had been sprayed with a herbicide.

Photo 25. Capsicum "Warlock" grown on a conventional plasticulture system with intensive tillage (top); on permanent beds with zone tillage and sorghum residue bed mulch (centre); and on permanent beds with zone tillage and polyethylene film mulch (bottom), in the second crop season in 2012 (15 July) in the trial at Bowen, Qld.

Permanent bed + zone tillage | Permanent bed + zone tillage + polyethylene mulch | Conventional intensive tillage

Photo 26. Capsicum plants 39 days after transplanting in three tillage systems in the field trial at Bowen in 2012 (Left to right: treatments PB_{zt}, PB_{poly}, and IT). Weeds in inter rows had been sprayed with herbicide.

Permanent bed + zone tillage | Permanent bed + zone tillage + polyethylene mulch | Conventional intensive tillage

Photo 27. Capsicum plants 96 days after transplanting in three tillage systems in the field trial at Bowen in 2012 (Left to right: treatments PB_{zt}, PB_{poly}, and IT).

Photo 28. Capsicum plants 104 days after transplanting in permanent beds with zone tillage in the field trial at Bowen in 2012 (Treatments PB_{zt}).

Photo 29. Bed soil surface 104 days after planting a capsicum crop on permanent beds with polyethylene film mulch (left) and on annual beds with intensive tillage and polyethylene mulch (right) in 2012.

Photo 30. Zucchini "Nitro" grown on a conventional plasticulture system with intensive tillage (top); on permanent beds with zone tillage and sorghum residue bed mulch (centre); and on permanent beds with zone tillage and polyethylene film mulch (bottom), in the second crop season in 2012 (15 July) in the trial at Bowen, Qld.

Permanent bed + zone tillage

Permanent bed + zone tillage + polyethylene mulch

Conventional intensive tillage

Photo 31. Zucchini plants 39 days after transplanting in three tillage systems in the field trial at Bowen in 2012 (Left to right: treatments PB_{zt}, PB_{poly}, and IT). Plants were in their first week of harvest. Weeds in inter rows had just been sprayed with herbicide.

5.10. Pest and disease management

Aphids, green peach (*Myzus persicae*) and melon aphid (*Aphis gossypii*) were the main pest in capsicums in 2012. A reduction in aphids followed after three releases of the commercially available parasitic wasp *Aphidius colemani*. European earwig (*Forficula auricularia*) became a pest in one block of a commercial farm. This insect has been known to cause damage to crops under minimum till systems with organic mulch. Under these systems control would be limited to bait with chemicals, trapping systems, diatomaceous earth applications.

Foliar diseases in zucchini were managed with one systemic application of Acrobat + Mancozeb a week after transplanting, followed by phosphorus acid (Agri-Fos 600) a week later and, thereafter, alternated weekly sprays of copper octanoate (Tricop) and micronized sulphur (Microthiol Disperss). This spray program was tested in VG07127 "Integrated management of foliar diseases in vegetable crops" and have also proved to give good control of powdery and downy mildews (*Podosphaera xanthii*, *Pseudoperonospora cubensis* respectively) in this project when used in conjunction with genetic materials with acceptable resistance to foliar diseases. There were no foliar or soil borne diseases in capsicum. There were no symptoms of virus in zucchini or capsicum.

Photo 32. Mummified aphids from parasitism by the micro wasp *Aphidius colemani* and supplementary aphid management by natural lady beetle larvae (left). Use of an air-assisted boom sprayer over zucchini plants for an effective coverage of alternative products to systemic fungicides in the Bowen trial. Severity caused by downy mildew and powdery mildew was very low under the spray program that was followed.

6. New South Wales Field Trial

6.1. Introduction

The Sydney basin has a long history of vegetable production in Australia. Surveys have identified significant soil degradation, in particular depletion of soil organic carbon and accumulation of extractable phosphorous (P) (Chan et al., 2007a). Conventional vegetable farming systems in Sydney commonly involve frequent tillage and high inputs of poultry manure and inorganic fertilisers (Chan et al., 2007b). Vegetable farms in the region are regarded as a source of the P that enters local waterways (Hollinger et al., 2001; Chan et al., 2010). It is important that alternative management practices are developed to improve the sustainability of intensive vegetable production in peri-urban areas like Sydney (Chan et al., 2007a).

Organic amendments are one option for reversing soil degradation and recycling waste products. Garden organic compost is organic rich material produced after the composting of source separated green waste from households and municipal areas. After composting, the material is separated into a fine soil conditioner and a coarse mulch product. These products are currently used in urban or landscaping situations in the Sydney basin but intensive vegetable production is an alternative market worth investigating. Overseas work using compost from garden organics found that high annual application rates applied as a single dose improved soil properties, although vegetable responses are only likely where native soil fertility is low (Evanylo 2002).

A field trial was established in 2005 to evaluate the effectiveness of garden organic compost as an alternative soil input for vegetable production in the Sydney basin. The research objectives for the field trial were to

(i) evaluate the effect of compost on vegetable production and soil quality relative to conventional farmers practice,

(ii) compare vegetable production under high and low soil P, and

(iii) monitor changes in soil P concentration under compost treatments relative to conventional farming practice.

A long-term field trial of this magnitude is a costly but valuable resource. It is important that the long-term effect of a practice change is investigated to determine if it is a sustainable option for grower adoption. The NSW long term field trial has been funded by a significant commitment from NSW DPI throughout the life of the trial, the NSW Department of Environment and Heritage (crops 1-5), the Australian Centre for International Agricultural Research (crops 6-10) and HAL project VG09038 ‘Vegetable soil health systems for overcoming limitations causing soil-borne diseases’ since January 2010 (crops 8-13).

6.2. Methods

a. Site and Soil Characteristics

The field trial was located at the NSW DPI Centre for Recycled Organics in Agriculture near Camden (70m AHD at 150º 42´32˝E, 34º 05´45.6˝S), NSW, Australia. The site has a long history of forage and intensive cropping production and was under lucerne pasture prior to the field experiment. The soil type at the site was a Chromosol/Dermosol inter-grade (Isbell 1996), with a hardsetting topsoil. The basic soil characteristics are described in Chan *et al*. (2008) and Chan *et al*. (2010).

b. Treatments and Experimental Design

The trial involved seven treatments organised in a randomised complete block design of 4 replicates (Figures 6-1 and 6-2). Plot size was 5 m by 6 m with a 1 m buffer between plots. Three beds (1.2 by 6.0 m) were formed within each plot. The treatments were:

T1 = high P, conventional practice (fertiliser and poultry manure);

T2 = high P, compost (125 dry t/ha);

T3 = high P, compost (62.5 dry t/ha) and fertiliser (½:½);

T4 = low P, conventional practice (fertiliser and poultry manure);

T5 = low P, compost (125 dry t/ha);

T6 = low P, compost (62.5 dry t/ha) and fertiliser (½:½);

T7 = control (nil input).

The compost was obtained from a commercial supplier and was typical of commercially available blends (Chan et al. 2007b). It was derived from source separated garden organics blended with 10% poultry manure (laying chickens), was composted according to the Australian Standard AS 4454-2003 and is described in Table 6-1. It was applied at the start of the trial and after the 5th and 10th crops (Figure 6-1 b and c).

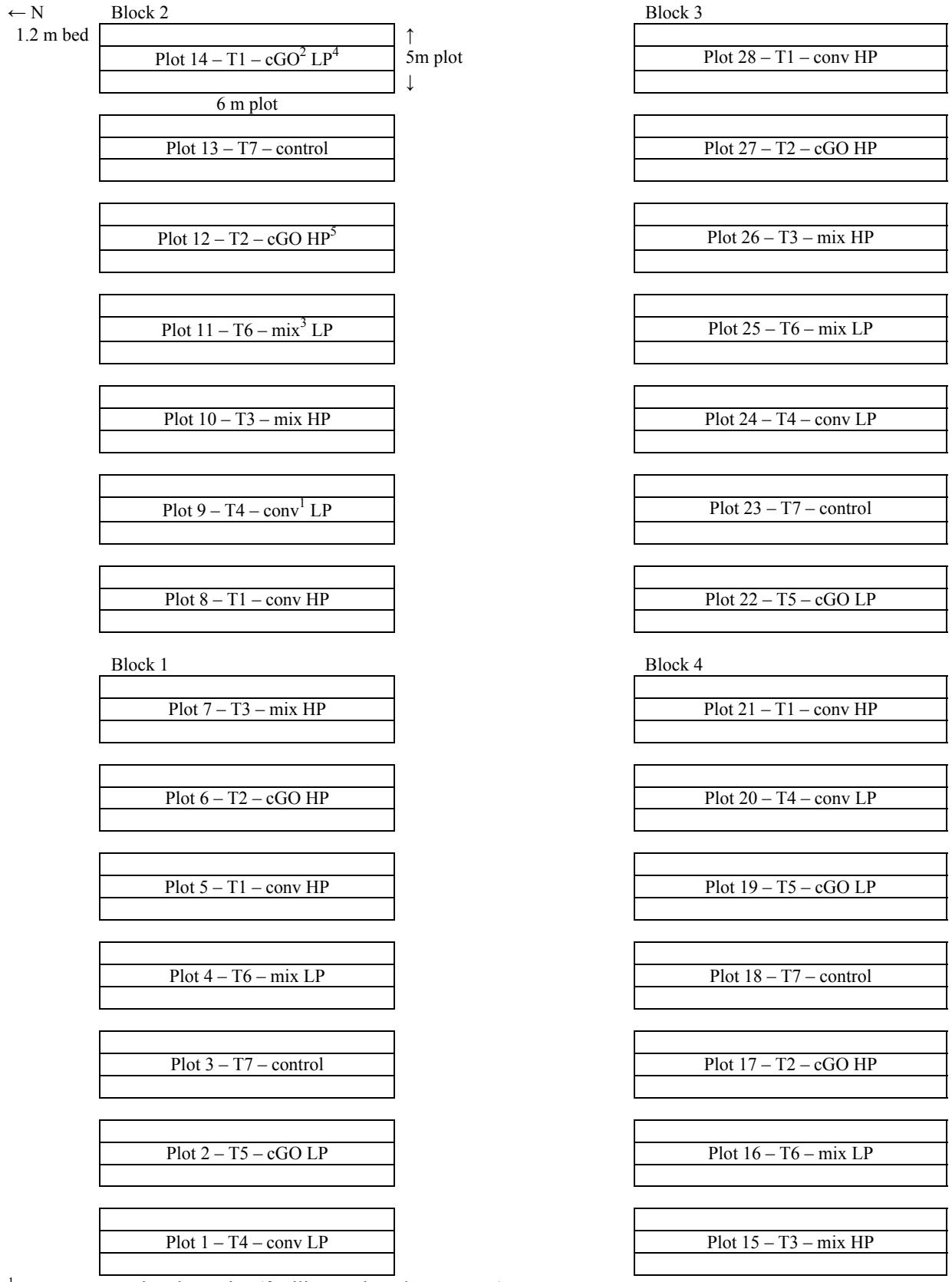
a.

b.

c.

Figure 6-1: NSW DPI CROA vegetable trial – a. field trial; b. weighing of compost (cGO) for application to appropriate treatment plots; c. field trial with compost applied

Figure 6-2: NSW DPI CROA vegetable trial – field trial plan showing treatment



[1]conv = conventional practice (fertiliser and poultry manure)
[2]cGO = garden organic compost (125 dry t/ha)
[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)
[4]LP = low phosphorous / [5]HP = high phosphorous

Table 6-1: NSW DPI CROA vegetable trial – properties of soil (T = 0) and compost used in the trial

Substrate	**Properties**								
Soil	pH_{Ca}†	EC‡ dS/m	TOC g/100g	TN g/100g		Exchangeable cations, cmol (+)/ kg			
					Colwell P mg/kg	Na	K	Ca	Mg
0-10 cm	5.2	0.13	1.1	0.11	29	0.12	0.29	5.35	1.25
	pHw‡	EC dS/m	TOC g/100g	TN g/100g	C/N	TP g/100g	Colwell P mg/kg		
Compost no.1 (C1)	5.6	3.14*	21	1.1	19.1	0.38	1200		
Poultry manure C1-10	8.1	9.20	32	3.1	10.3	2.60	7500		
Compost no.2 (C6)	6.9	5.3	30	1.6	18.8	0.72	2200		
Compost no. 3	6.9	3.5	17	1.0	17	0.36	720		

† pH in 1:5 soil/0.01 M CaCl2; ‡electrical conductivity and pHw in 1:5 soil: water extract; TOC= total organic carbon; TP= total P

Poultry manure and triple superphosphate were applied to the conventional treatment plots (T1, T4) and triple superphosphate was applied to the mixed treatments (T3, T6) before bed formation in every crop. All fertiliser treatments (T1, T3, T4, T6) received potassium (muriate of potash) and nitrogen (urea) as needed during the crop cycle based on soil and plant sap tests respectively. Nutrient requirements for the different crops were based on industry expert recommendations. The compost treatments (T2, T5) received no chemical fertiliser inputs until the 4th and 5th crops following the first compost application, at which point nitrogen was supplied as urea when deemed necessary by sap test comparison with the conventional treatment plot crops (T1, T4). Following the 2nd 125 dry t/ha application of compost, no chemical fertiliser was applied to the compost plots of crops 6, 7 and 8 and following the 3rd 125 dry t/ha compost application no chemical fertiliser was applied to the compost plots of crops 11 and 12.

The production cycle is outlined in Table 6-2. Crops were drip irrigated, with irrigation scheduling based on soil moisture sensors placed in two plots in two different blocks. Further details about the trial site are available in Chan *et al*. (2008) and Chan *et al*. (2010).

Table 6-2: NSW DPI CROA vegetable field trial production cycle 2005-2013

Activity	Description	Timeframe
Compost application 1		April 2005
Crop 1	broccoli	April – Aug 2005
Crop 2	eggplant	Dec 2005 – Mar 2006
Crop 3	cabbage	May – Aug 2006
Crop 4	capsicum	Dec 2006 – April 2007
Crop 5	leek	July – Oct 2007
Compost application 2		Aug 2008
Crop 6	capsicum	Oct 2008 – Mar 2009
Crop 7	broccoli	June – Oct 2009
Crop 8	lettuce	Feb – April 2010
Crop 9	cabbage	July – Nov 2010
Crop 10	sweet corn	Feb – May 2011
Compost application 3		Aug 2011
Crop 11	capsicum	Oct 2011 – Mar 2012
Crop 12	cabbage	July – Dec 2012
Crop 13	oats – green manure	July 2013 – in progress

c. Soil Sampling and Analyses

Soil samples were collected from each plot after transplanting of each crop about 2 days after irrigation. Soil samples were also collected at harvest for crops 5 onwards. In each plot, 7 soil cores (0.05 m diameter, 0.15 m depth) were collected from the 3 beds. All samples from the one plot were bulked to form a composite sample which was weighed and mixed. Subsamples for biological measurements were stored at 4ºC until analysed. Samples for nematode analysis were kept out of the sun and cooled, but not refrigerated before transport to Qld DAFF for processing.

Field moist soils (at close to field capacity) were sieved using a 2 mm sieve to remove all stones, macrofauna and roots. Samples were stored in loosely sealed bags to allow gaseous exchange.

A number of biological, chemical and physical parameters were measured in soil sampled from all crops grown.

d. Production data

All beds across the trial were harvested but production data was obtained from the middle bed of each plot. All non-marketable crop residues were incorporated by rotary hoeing.

Fresh weights were determined for each plot for each crop harvest. Additional market measurements (e.g. number of lettuce heads per standard market box, number of corn cobs per market box and number of boxes per plot; Figure 6-3) were also recorded for certain crops if relevant to economic analyses. A subsample of each fresh crop sample was weighed and dried at 80ºC to constant mass, re-weighed and then ground for subsequent elemental analysis of N, P, K, Ca, Mg, Na, and Cl. Nitrogen was determined by Dumas combustion, chlorine calorimetrically after acetic acid extraction, and phosphorous as well as cations determined by ICP-AES after acid digestion (USEPA 1996, Kalra 1998).

Figure 6-3: NSW DPI CROA vegetable trial – showing the packing of produce into containers of relevance to growers; L to R lettuce and corn cobs in commercial boxes

e. Biological indicators

The following biological soil parameters were measured:

Biological indicator	Test	Crops measured
Biological activity	Basal respiration	1-7
Microbiological activity	Microbial biomass carbon by chloroform fumigation extraction	1-12
Microbiological activity	Hydrolysis of fluorescein diacetate (FDA)	6-12
Microbial diversity & activity	Microbial community analysis using Biolog ECO plate	8-12
Biological diversity	Nematode community analysis	8-12

Basal Soil Respiration

Basal soil respiration was measured using the method of Anderson (1982). A 50 g portion of field moist soil was weighed into a glass vial placed in a sealable container (100 ml glass jar with plastic screw on lid). A second glass vial containing 10 ml 0.5 M KOH was placed into the same container. Ten ml de-ionised water was pipetted into the bottom of the container. The container was sealed and incubated at 25ºC for 7 days. At the end of the incubation period, the container was opened and the amount of carbon dioxide produced was determined by titration. The respiration rate was calculated by dividing the respired CO_2 by the time of incubation. Two replicates were analysed for each plot.

Microbial Biomass Carbon

Microbial biomass C was determined using the chloroform fumigation extraction method of Vance et al. (1987). A 20 g portion of field moist soil was weighed into a beaker, with 6 replicates prepared for each sample. Three of the soil portions were fumigated using purified chloroform in a vacuum desiccator placed in the dark at 25ºC overnight (18-24 h). The 3 other soil portions were placed inside desiccators but without chloroform fumigation. The soil portions were then extracted using 80 ml of 0.5 M K_2SO_4. Total dissolved carbon of the soil extracts was measured using a Carbon Analyzer (Shimadzu) to measure the organic carbon in the aqueous solution (Wu et al., 1990). Biomass carbon was then calculated from the difference in carbon between the fumigated and non-fumigated soils and using a conversion factor of 2.64 (Wu et al., 1990).

Hydrolysis of Fluoroscein Diacetate (FDA)

The method used for measurement of FDA hydrolysis was based on Green et al. (2006). A 1g soil sample (3 replicates tested per bulked soil sample) was added to 50 ml of 60 mM sodium phosphate buffer (pH 7.6) in a 50 ml tube. 0.50 ml of 4.9 mM FDA substrate solution was added before incubating at 37 °C for 3 h. The reaction was then stopped by adding 2 ml of acetone. A 30ml sub aliquot of the suspension was centrifuged at 8000 rpm for 5 mins (Sovral RC5). The supernatant was filtered (Whatman No.2) and 250 µl of filtrate from each sample was loaded onto a black 96-well plate (Nunc Black Microwell SI) along with the standards. Fluorescence was measured at 485 nm (excitation) and 535 nm (emission) using a Fluoroskan Ascent FL microplate reader (Thermo Electron Corporation, Vantaa, Finland). The amount of FDA hydrolysed was determined in reference to the standard curve.

Biolog ECO plate

Microbial diversity and abundance was measured using Biolog ECO plates (Treseder et al. 2004). Soil samples were serially diluted in sterile milli Q water (1:10, 1:100, 1:1000 and 1:10000) and incubated at 25ºC in Biolog ECO plates (3 replicates per bulked soil sample). Readings were recorded at plate set up and then every 24 hours for 4 days at 595nm using a Multiskan plate reader. The average absorbance of the 3 replicates was used to calculate the average all well colour development (AWCD) for each soil sample.

DNA Analysis

Samples collected prior to harvest of the second capscium crop were submitted for DNA analysis at the Horticulture Pathology Diagnostic Service, Plant Research Centre, South Australian Research and Development Institute. DNA was extracted and quantitative PCR was performed to identify levels of 14 fungi present in the soil.

Nematode community analysis

Soil samples were collected at planting of the lettuce crop and at harvest of crops 8-12 and submitted to the Queensland DAFF project team (Jenny Cobon and Tony Pattison) for processing and analysis.

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g of field moist soil sub-sample was weighed onto a mesh sieve with a single ply of tissue and placed into a tray with 250 mL of water for 48 hours. The nematodes were collected on a 25 µm sieve and backwashed into a vial. The total number of nematodes was estimated and a 50 µL aliquot was placed on a glass slide. A minimum of 100 individual nematodes were identified to genus for plant-parasites and family for free-living nematodes.

Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators). Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index and the ratio of bacterivores and fungivores calculated (Yeates and Bongers 1999). Additionally, the weighted functional guilds analysis concept was applied, without plant parasites to determine the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris et al. 2001).

f. Chemical and physical analyses

Soil samples were allowed to air dry. Dried <2 mm soil samples were analysed for pH, electrical conductivity (EC), exchangeable cations and effective cation exchange capacity

(eCEC), total carbon (C), total nitrogen (N), and bicarbonate extractable P (Colwell P). The soil pH_{CaCl2}, EC and C were determined according to methods of Rayment and Higginson (1992). The exchangeable cations were determined following the compulsive exchange method of Gillman and Sumpter (1986) as documented in Rayment and Higginson (1992). Total C and N were determined by Dumas dry combustion as documented in Rayment and Higginson (1992). Mineral N (NO_3^--N and NH_4^+-N) were determined on a 1:5 extraction with 2M KCl according to Rayment and Higginson (1992).

Soil structural stability

Air dry soil samples were first passed through a 9.5mm sieve. 20 g subsamples were weighed and wet sieved for 10 min with a 38 mm stroke length and 30 strokes/min using 2 mm sieve mounted over a 250 µm sieve, in a 2L cylindrical container of deionised water. The 20 g subsample of air dry soil was initially gently placed in the top sieve (i.e. 2mm aperture sieve) prior to the wet sieving, and then at the end of the wet sieving the soil collected in each of the two sieves was gently washed into a container and oven dried at 105 ºC, along with a subsample of the air dry soil (for conversion of 20 g to oven dry equivalent weight) to allow the determination of the percentage of water stable aggregates in each particle size range. Wet sieving was carried out in duplicate for each sample, and the percentages of water-stable aggregates >2mm and >250 µm diameter were calculated as the mean of the two measurements per sample.

Penetrometer measurements of soil compaction / hardpan formation

A data logging Rimik CP10a cone penetrometer (Agridry Rimik Pty Ltd, Toowoomba) was used to measure the soil resistance to the insertion of a penetrometer in each treatment plot. Measurements were done when soil moisture conditions were close to field capacity down to 50 cm on inspection, usually a couple of days following rainfall events. The penetrometer was inserted into the middle of each of the three beds within each plot down to a depth of 450 mm, with the penetrometer logging soil penetration resistance (kPa) every 15mm down the profile. The penetrometer then averaged the three readings and recorded this as one average profile measurement for each plot. This was done at the end of crop 10.

g. Economic analyses

A financial analysis was conducted of the trial results for vegetable crops 1-10 grown between 2005 and 2011, and the benefit cost ratio of the compost and mixed treatments versus the farmer practice were compared.

h. Statistical Analyses

The phosphorus treatment effects on biological, chemical and physical soil parameters were analysed using the conventional block design analysis of variance. Protected F least significant differences (l.s.d.) were calculated at 5% level for comparing pair-wise treatment effects. A logarithmic transformation of the data was sometimes required (e.g. Colwell P, nitrate) prior to analysis.

Nematode data was log transformed prior to analysis to reduce the variance heterogeneity. All parameters were estimated using the residual maximum likelihood (REML) technique. L.s.d. at the 5% level was used to tests significances between levels of each factor.

6.3. Results

Crops 1 to 7

Results from the field trial found that one compost application applied at an agronomic rate of nitrogen (125 dry t/ha) produced similar or higher yields than that of current farmer's practice in the subsequent 5 crops grown (Chan *et al*. 2008; Chan *et al*. 2010; Chan *et al*. 2011). For crop 4 (capsicum), yield of the compost treatments was 21% higher than farmer's practice. The compost treatment also had a 36% saving in urea, and a 100% saving in P and K fertiliser. Benefit cost analyses calculated that the compost provided a benefit cost ratio of 1 after 5 crops (Chan *et al*. 2011). After the second compost application of 125 dry t/ha, the compost treatments out yielded farmer's practice by nearly 90% in the first crop grown (capsicum) but comparable yields were produced in subsequent crops.

This study found that a compost application of 125 dry t/ha significantly enhanced soil biological properties but this benefit diminished over time as consecutive crops were grown (Figure 6-4). A repeat application of compost before the sixth crop had a greater influence on soil biological activity. It also appears that the significant residues from the sweet corn crop significantly increased organic carbon in all treatments. Compost application significantly improved a number of other soil properties, including soil carbon (Figure 6-5), exchangeable cations and structural stability, compared with conventional farmers' practice (Chan *et al*., 2008).

The results of the field trial revealed that there was no agronomic benefit to maintaining the soil at a high P status and the high levels of extractable soil P currently found in vegetable farms around Sydney are not necessary for maintaining productivity. These high P levels are excessive and of environmental concern due to the off-site impacts including potential for leaching and water pollution (Wells *et al*., 2000; Chan *et al*., 2007a; Chan *et al*., 2010).

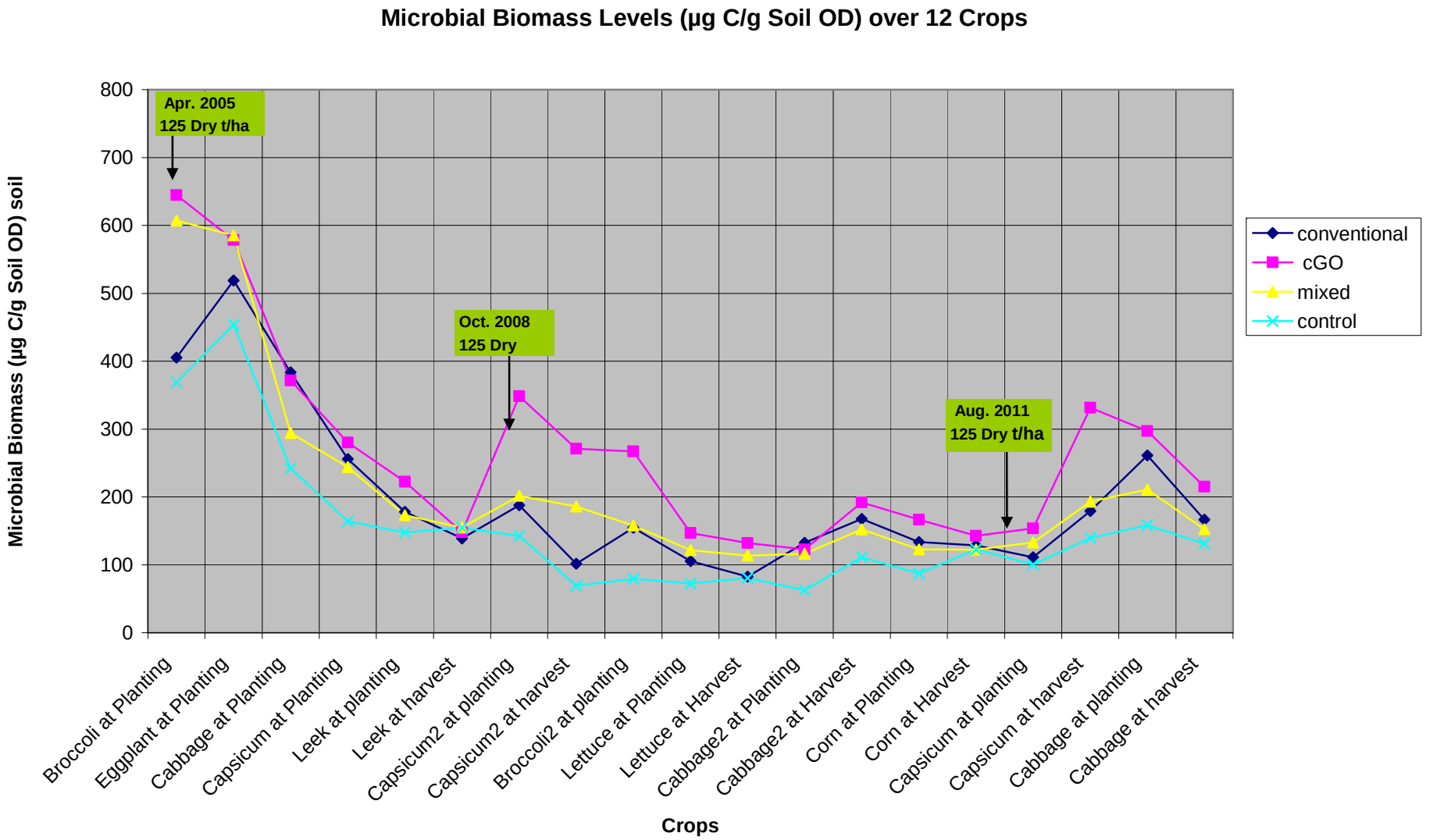


Figure 6-4: NSW DPI CROA vegetable field trial – effect of compost on microbial biomass C (µg C/g soil OD) over 12 crops

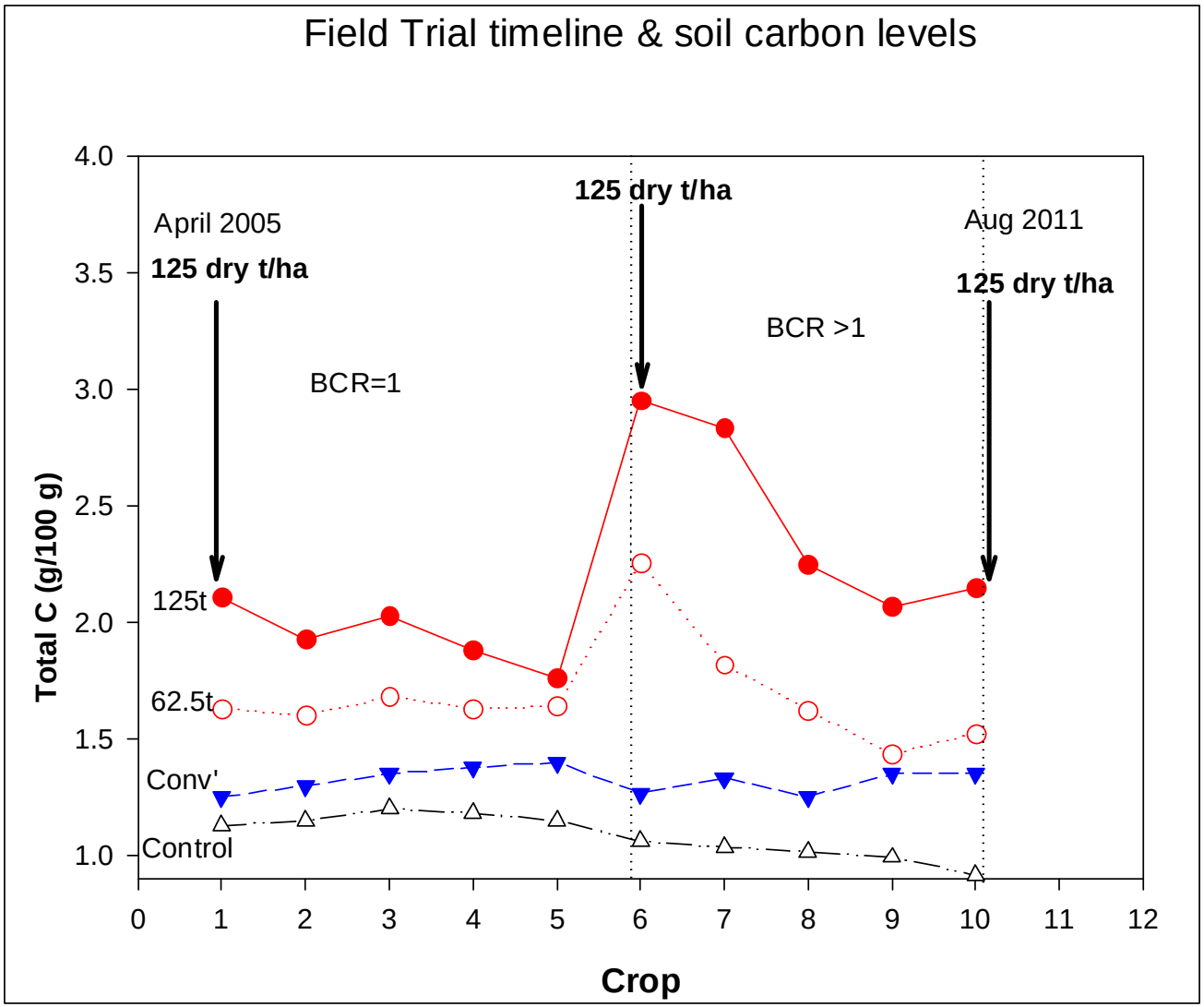


Figure 6-5: NSW DPI CROA vegetable field trial – effect of compost application on soil carbon levels over 10 crops (Total C (g/100g) versus crop)

Crops 8 to 12

a. Production

Compost treatments produced significantly higher yields than farmers practice and mixed treatments in the lettuce crop (as measured by fresh weight; Table 6-3; Figure 6-6) where the full compost treatment (T5) yield of 47 t/ha was 24.7% higher than the farmer practice treatment (T4) yield of 37.7 t/ha. No significant difference was found between the lettuce yields of the mixed and farmer practice treatments. The only significant treatment differences in the cabbage and corn crops were the significantly lower yields in the control plots as measured by fresh weight (Table 6-3; Figure 6-7). The 11th crop was the third capsicum crop grown and the first crop grown after the 3rd application of compost. However, there were seasonal and management issues which meant that the weed population built to a competitive level in all plots. This provided an opportunity to see how the compost amended plots performed in a 'stress' situation. Production values were low but the compost amended plots outyielded all other treatments, these differences were significant in the high P plots (Table 6-3). The compost amended treatments gave greater yields in the 12th crop of cabbage but this was only statistically significant when compared with the control (Table 6-3). There was no benefit to maintaining the soil at a high P status for any crops grown in the field trial.

The quality of the vegetable produce from each treatment was compared on the basis of the analysis of the harvestable part of the crop for common elements; chloride, calcium, potassium, magnesium, sodium, phosphorus, sulphur, and nitrogen (Table 6-4).

The potassium (K) content of the produce from both the compost and mixed treatments was significantly ($P<0.05$) higher (22 to 46% higher) than levels found in the produce from the conventional treatments for crop 8 (lettuce) which was also the case for the preceding crops 6 and 7 (data not reported) which followed the 2nd application of compost. The differences in K levels were less distinct in the later crops (crop 9 cabbage, crop 10 corn). Another notable result with implications for human health, was the significant difference ($P<0.05$) in the sodium content of the harvestable produce between the compost treatment and the farmer practice for crop 8 (lettuce). The mean sodium contents of the lettuce crop harvested from the compost (T5) and mixed treatments (T6) were 0.15% and 0.25% respectively compared with the produce harvested from the conventional farmer practice treatments with a mean sodium content of 0.48%. However no significant differences were found in the subsequent cabbage and sweet corn crops. This reflects the soil exchangeable K levels, which indicate a significant depletion, most likely due to leaching.

The crop quality results for crop 11 (capsicum), which followed the third compost application for the compost and mixed treatments reflect the impact of the high weed population in this crop. The stress situation created by the weeds affected nutrient availability and yield and is likely to have masked any treatment effects that might otherwise have been apparent. The high variability in yield data for crop 12 (cabbage) indicates an underlying soil problem, which is especially apparent if one compares these yields with that of the previous cabbage crop grown in this field trial (crop 9) (Table 6-3). Prior to this crop there was detection of some evidence of subsoil compaction, and there was an intention to deep rip the site prior to the planting of crop 12. This was abandoned due to the subsoil being too moist for deep ripping in the lead up to crop 12. Subsoil compaction is believed to be the most likely cause of the low yields, given there were no observations of nutrient deficiency symptoms in the crop. Few significant differences are apparent in the crop composition data (Table 6-4), and this is not surprising given the high variation in yield from this crop.

Figure 6-6: NSW DPI CROA vegetable field trial – lettuce crop block 1 2010 - L to R middle beds of control, mixed, cGO and conventional treatments

Figure 6-7: NSW DPI CROA vegetable field trial – cabbage crop 2010 – L to R middle beds and example of heads from control, mixed, cGO, conventional treatments

Table 6-3: NSW DPI CROA vegetable field trial - Effect of compost application on crop production in 5 vegetable crops grown (means followed by the same letter are not significantly different)

Treatment	Crop 8 Lettuce	Crop 9 Cabbage	Crop 10 Corn		Crop 11 Capsicum		Crop 12 Cabbage
	Fresh weight (t/ha)	Fresh weight (t/ha)	Fresh weight (t/ha)	Cobs / box	Fruit number / middle plot	Fresh weight (t/ha)	Fresh weight (t/ha)
conventional[1] HP[4]	38.34 c	55.35 a	22.21 a	16.29 a	17.5 abc	3.64 bc	10.75 ab
cGO[2] HP	45.6 ab	57.41 a	25.55 a	16.32 a	36.5 a	9.01 a	19.32 a
mix[3] HP	41.49 bc	52.86 a	22.78 a	15.54 a	10 c	2.07 bc	17.18 ab
conventional LP[5]	37.73 c	54.11 a	22.69 a	15.72 a	26.5 abc	5.94 abc	18.13 ab
cGO, LP	47.04 a	49.04 a	24.44 a	15.60 a	29.25 ab	6.57 ab	14.41 ab
mixed, LP	41.89 bc	58.88 a	25.28 a	16.19 a	23 abc	4.95 abc	15.54 ab
control	15.84 d	28.60 c	13.78 b	17.11 a	8.25 c	1.45 c	6.55 b
lsd 5%	4.82	14.92	3.96	1.66	19.55	4.74	11.71

[1]conventional = conventional farmer practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous

[5]LP = low phosphorous

Table 6-4: NSW DPI CROA vegetable field trial – Effect of compost application on crop quality in 5 vegetable crops grown

Treatment	Chloride	Ca	K	Mg	Na	P	S	N
Crop 8 - Lettuce								
T1 – conventional[1] HP[4]	1.73bc	0.83d	4.63c	0.33b	0.52b	0.66b	0.24	3.65c
T2 – cGO[2] HP	1.63c	1.01ab	6.75a	0.30c	0.24de	0.67b	0.26	4.10a
T3 – mix[3] HP	1.98b	1.10a	6.28ab	0.34b	0.33cd	0.75a	0.28	3.88b
T4 – conventional LP[5]	1.73bc	0.87cd	4.60c	0.32b	0.48bc	0.67b	0.24	3.63c
T5 – cGO LP	1.50c	0.89cd	6.10ab	0.28c	0.15e	0.66b	0.26	3.85b
T6 – mix LP	1.65c	0.94bc	5.58b	0.29c	0.25de	0.66b	0.25	3.83b
T7 – control LP	2.33a	0.85cd	3.88c	0.43a	0.81a	0.40c	0.27	3.25d
lsd (P=0.05)	0.28	0.11	0.92	0.04	0.15	0.08	NS	0.22
Crop 9 - Cabbage								
T1 – conventional[1] HP[4]	0.57a	0.81	3.93ab	0.30a	0.46	0.68ab	1.07	3.53ab
T2 – cGO[2] HP	0.47bc	0.81	3.45b	0.28ab	0.42	0.63b	1.01	3.35bc
T3 – mix[3] HP	0.53ab	0.76	3.48b	0.27ab	0.42	0.63b	0.98	3.28bc
T4 – conventional LP[5]	0.50abc	0.78	3.45b	0.27ab	0.45	0.64ab	1.00	3.38bc
T5 – cGO LP	0.43c	0.83	3.53a	0.28ab	0.36	0.61b	1.01	3.40bc
T6 – mix LP	0.60a	0.86	4.03a	0.30a	0.44	0.71a	1.06	3.70a
T7 – control LP	0.46bc	0.69	2.85c	0.26b	0.37	0.36c	1.00	3.18c
lsd (*P*=0.05)	0.10	NS	0.50	0.03	NS	0.07	NS	0.30
Crop 10 - Sweet Corn								
T1 – conventional[1] HP[4]	0.18	0.04b	1.04	0.13ab	<0.01	0.36a	0.11	1.38
T2 – cGO[2] HP	0.17	0.03b	1.04	0.12b	<0.01	0.35ab	0.11	1.38
T3 – mix[3] HP	0.16	0.03b	1.02	0.12b	<0.01	0.35ab	0.11	1.45
T4 – conventional LP[5]	0.17	0.04b	1.03	0.13ab	<0.01	0.34ab	0.11	1.40
T5 – cGO LP	0.16	0.03b	1.01	0.12b	<0.01	0.33bc	0.11	1.48
T6 – mix LP	0.19	0.04b	1.03	0.12b	<0.01	0.31c	0.11	1.33
T7 – control LP	0.22	0.05a	1.04	0.14a	<0.01	0.26d	0.11	1.33
lsd (*P*=0.05)	NS	0.01	NS	0.01	NS	0.02	NS	NS
Crop 11 - Capsicum								
T1 – conventional[1] HP[4]	0.378	0.178	3.425	0.188	0.0185	0.510	0.278	2.525
T2 – cGO[2] HP	0.290	0.175	3.425	0.185	0.0165	0.503	0.270	2.475
T3 – mix[3] HP	0.345	0.178	3.400	0.180	0.0175	0.485	0.275	2.525
T4 – conventional LP[5]	0.350	0.178	3.100	0.178	0.0158	0.478	0.260	2.500
T5 – cGO LP	0.295	0.170	3.425	0.173	0.0178	0.465	0.258	2.450
T6 – mix LP	0.320	0.193	3.525	0.180	0.0178	0.485	0.273	2.625
T7 – control LP	0.448	0.150	2.525	0.163	0.0158	0.363	0.238	2.500
lsd (*P*=0.05)	0.071	0.049	0.374	0.021	0.002	0.043	0.029	0.347
Crop 12 - Cabbage								
T1 – conventional[1] HP[4]	0.528	0.600	3.00	0.185	0.130	0.488	0.778	2.650
T2 – cGO[2] HP	0.590	0.630	3.267	0.203	0.137	0.520	0.820	2.900
T3 – mix[3] HP	0.508	0.560	2.800	0.185	0.120	0.468	0.755	2.550
T4 – conventional LP[5]	0.517	0.613	3.133	0.207	0.123	0.520	0.793	2.900
T5 – cGO LP	0.490	0.635	3.150	0.183	0.099	0.503	0.830	2.600
T6 – mix LP	0.460	0.550	2.967	0.157	0.073	0.473	0.723	2.300
T7 – control LP	0.548	0.613	3.000	0.190	0.122	0.493	0.788	2.700
lsd (*P*=0.05)	0.113	0.058	0.352	0.024	0.060	0.044	0.075	0.231

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½) / [4]HP = high phosphorous / [5]LP = low phosphorous. Crop means in columns with different letters following are significantly different from one another $p < 0.05$. NS no significant difference $p > 0.05$.

b. Soil biological properties

Microbial biomass carbon was significantly higher in soils from the compost treatments compared to farmer's practice for crop 8, with the mixed treatment (½ conventional:½ compost) showing values in between (Figure 6-4; Table 6-5). Subsequent crops 9 and 10 showed similar trends but the differences were not statistically significant. The next crop grown after the third compost application (crop 11) was capsicum and soil sampled from the compost treatments measured significantly greater levels of biomass carbon than soil from both the conventional and mixed treatment plots. Again similar trends were observed in the subsequent crop (12) but the differences were only statistically significant in comparison to the untreated control (Figure 6-4; Table 6-5).

Biolog Ecoplate responses by the microbial communities in each treatment were expressed by AWCD (all well colour development). AWCD was significantly greater in the compost treatments for the lettuce crop (Table 6-6). In contrast biological activity as expressed by hydrolysis of fluorescein diacetate (FDA) was generally lower in soil collected from the full compost treatment compared to farmer's practice for the lettuce and cabbage crops but greater in the capsicum crop grown after the 3rd compost application (Table 6-7). No other significant treatment differences or consistent trends were detected and there appeared to be no effect of phosphorous on any of the biological properties measured.

The compost amended soils had significantly lower numbers of plant parasitic nematodes compared to the conventional treatment in soil samples collected at harvest from the lettuce (crop 8), corn (crop 10) and cabbage (crop 12) crops (Table 6-8). Significantly greater numbers of predatory nematodes were recorded in compost amended soils collected at the harvest of crops 9, 10 (low P only) and 11 (high P) (Table 6-9). Nematode diversity, as measured using the Shannon-Weiner diversity index, did not exhibit significant trends across the crops although the diversity was greater in compost amended soils collected from the lettuce (at planting) and cabbage crops (Table 6-10). The structure index is based on the proportion of predatory nematodes in the community and gives an indication of the condition of the soil food web. The structure index was generally higher in the compost amended soils of crops 10 and 11 after the 3rd compost application. However, there were no consistent trends in the population of bacterial versus fungal feeding nematodes extracted from soil samples (Table 6-11).

Table 6-5: NSW DPI CROA vegetable field trial - Effect of compost application on soil biological activity (mean soil microbial biomass carbon) in soil samples collected at time of crop harvest in 5 vegetable crops grown (means followed by the same letter are not significantly different from one another $p < 0.05$)

Treatment	P status	Input	Mean soil microbial biomass (µg C/g OD soil)				
			lettuce crop 8	cabbage crop 9	corn crop 10	capsicum crop 11	cabbage crop 12
T1	High	Conventional[1]	82.4 b	173.0 abc	128.6 a	154.3 cd	162.4 ab
T2	High	Compost[2]	157.5 a	177.9 ab	134.8 a	279.7 b	210.8 a
T3	High	½ compost[3]	109.0 b	141.6 bc	131.6 a	198.2 cd	144.9 ab
T4	Low	Conventional	83.0 b	162.0 abc	128.8 a	204.1 c	171.1 ab
T5	Low	Compost	106.5 b	205.6 a	150.5 a	382.9 a	219.6 a
T6	Low	½ compost	118.0 ab	162.5 abc	112.7 a	187.4 cd	160.5 ab
T7	Control	Control	80.5 b	111.1 c	122.5 a	139.7 d	131.0 b
		l.s.d. 5%	48.2	62.9	44.3	64.4	76.5

[1]conventional = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

Table 6-6: NSW DPI CROA vegetable field trial - Effect of compost application on biological soil indicators (Biolog ECO plate AWCD) in soil samples collected at time of crop harvest in 5 vegetable crops grown (means followed by the same letter are not significantly different from one another p <0.05)

Treatment	P status	Input	Mean AWCD absorbance at 590nm / 96hr incubation			
			lettuce crop 8	corn crop 10	capsicum crop 11	cabbage crop 12
T1	High	Conventional[1]	0.0221 c	0.1364 bc	0.498 a	0.7214 ab
T2	High	Compost[2]	0.4056 a	0.0775 c	0.6138 a	0.6718 abc
T3	High	½ compost[3]	0.0912 bc	0.1885 ab	0.5584 a	0.6677 abc
T4	Low	Conventional	0.0039 c	0.1200 bc	0.4773 a	0.6205 bc
T5	Low	Compost	0.4446 a	0.1350 bc	0.5934 a	0.7026 abc
T6	Low	½ compost	0.1072 bc	0.0870 bc	0.5357 a	0.5906 c
T7	Control	Control	0.2178 b	0.2440 a	0.5383 a	0.7543 a
		l.s.d. 5%	0.1703	0.1030	0.4461	0.1157

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

Table 6-7: NSW DPI CROA vegetable field trial - Effect of compost application on soil biological activity (FDA) in soil samples from 5 vegetable crops grown (means followed by the same letter are not significantly different P = 0.05)

Treatment	P status	Input	Mean FDA fluorescence (µg FDA hydrolysed / g OD soil / min)				
			lettuce crop 8	cabbage crop 9	corn crop 10	capsicum crop 11	cabbage crop 12
T1	High	Conventional[1]	0.7893 a	0.7524 a	1.356 a	1.143 bc	1.539 a
T2	High	Compost[2]	0.6774 c	0.5743 c	1.295 a	1.329 a	1.37 bc
T3	High	½ compost[3]	0.6879 c	0.6199 bc	1.378 a	1.179 bc	1.284 b
T4	Low	Conventional	0.7847 ab	0.7140 ab	1.474 a	1.116 bc	1.415 ab
T5	Low	Compost	0.7042 bc	0.5865 c	1.230 a	1.467 a	1.32 bc
T6	Low	½ compost	0.6247 c	0.5607 c	1.356 a	1.281 ab	1.217 c
T7	Control	Control	0.6335 c	0.5725 c	1.367 a	1.059 c	1.242 bc
		l.s.d. 5%	0.0813	0.1274	0.277	0.1881	0.1742

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

Table 6-8: NSW DPI CROA vegetable field trial - Effect of compost application on plant parasitic nematode populations in soil samples collected for 5 vegetable crops grown (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	P status	Input	Total plant parasitic nematodes											
			lettuce crop 8				cabbage crop 9		corn crop 10		capsicum crop 11		cabbage crop 12	
			at planting		at harvest		at harvest		at harvest		at harvest		at harvest	
			mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L
T1	High	Conventional[1]	34.2	3.561 a	9	2.299 ab	2.13	1.139 a	37	3.637 a	960	6.868 a	6445	8.771 a
T2	High	Compost[2]	12.1	2.572 a	1.6	0.958 b	1.07	0.729 a	63	4.158 a	92	4.532 a	2217	7.704 b
T3	High	½ compost[3]	2.3	1.182 a	2.5	1.259 b	11.76	2.546 a	82	4.422 a	460	6.133 a	3477	8.154 ab
T4	Low	Conventional	20.7	3.078 a	29.4	3.414 a	2.46	1.243 a	36	3.620 a	413	6.025 a	4514	8.415 ab
T5	Low	Compost	22.1	3.139 a	2.8	1.322 ab	1.37	0.864 a	1	0.640 b	81	4.408 a	2538	7.839 b
T6	Low	½ compost	2.2	1.166 a	6.1	1.966 ab	3.77	1.562 a	42	3.765 a	894	6.797 a	3674	8.209 ab
T7	Control	Control	23.8	3.210 a	27.4	3.347 a	2.60	1.281 a	109	4.698 a	854	6.751 a	4647	8.444 ab
		l.s.d. 5%	-	3.647	-	2.146	-	2.118		2.455	-	2.608		0.743

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

L = Log transformed data

Table 6-9: NSW DPI CROA vegetable field trial – Effect of compost application on predatory nematode populations in soil samples collected for 5 vegetable crops grown (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	P status	Input	Total predatory nematodes											
			lettuce crop 8				cabbage crop 9		corn crop 10		capsicum crop 11		cabbage crop 12	
			at planting		at harvest		at harvest		at harvest		at harvest		at harvest	
			mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L	mean / 100g	L
T1	High	Conventional[1]	0.89	0.636 b	0.69	0.527 a	1	0.613 bc	1	0.692 bc	26	3.297 a	19.0	2.997 a
T2	High	Compost[2]	10.84	2.472 a	0.38	0.320 a	10	2.395 a	5	1.805 bc	94	4.549 a	17.8	2.932 a
T3	High	½ compost[3]	0.82	0.601 b	2.10	1.130 a	4	1.673 abc	7	2.096 b	14	2.731 a	3.3	1.467 a
T4	Low	Conventional	0	0 b	0	0 a	0	0 c	0	0 c	7	2.100 a	0	0 a
T5	Low	Compost	13.10	2.646 a	0.87	0.626 a	6	1.926 ab	78	4.37 a	11	2.449 a	4.3	1.659 a
T6	Low	½ compost	0.92	0.653 b	0	0 a	1	0.432 bc	7	2.028 b	32	3.491 a	14.2	2.724 a
T7	Control	Control	0.0	0 b	0	0 a	0	0 c	0	0 c	29	3.400 a	2.7	1.306 a
		l.s.d. 5%	-	1.53	-	1.213		1.770		1.872		3.825		4.571

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

L = Log transformed data

Table 6-10: NSW DPI CROA vegetable field trial - Effect of compost application on nematode diversity in soil samples collected for 5 vegetable crops grown (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	P status	Input	Shannon-Weiner diversity index					
			lettuce crop 8		cabbage crop 9	corn crop 10	capsicum crop 11	cabbage crop 12
			at planting	at harvest	at harvest	at harvest	at harvest	at harvest
T1	High	Conventional[1]	1.586 a	1.651 a	1.176 ab	1.802 a	1.728 a	1.590 ab
T2	High	Compost[2]	1.545 ab	1.651 a	1.147 ab	1.873 a	1.523 a	1.705 a
T3	High	½ compost[3]	1.622 a	1.694 a	1.233 ab	1.950 a	1.717 a	1.615 ab
T4	Low	Conventional	1.145 b	1.688 a	1.230 ab	1.755 a	1.732 a	1.510 b
T5	Low	Compost	1.639 a	1.372 a	1.002 b	1.724 a	1.662 a	1.591 ab
T6	Low	½ compost	1.512 ab	1.612 a	1.201 ab	1.922 a	1.709 a	1.591 ab
T7	Control	Control	1.613 a	1.626 a	1.345 a	1.953 a	1.758 a	1.568 ab
		l.s.d. 5%	0.407	0.325	0.312	0.231	0.375	0.193

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

Table 6-11: NSW DPI CROA vegetable field trial - Effect of compost application on nematode structure index in soil samples collected for 5 vegetable crops grown (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	P status	Input	Total plant parasitic nematodes											
			lettuce crop 8				cabbage crop 9		corn crop 10		capsicum crop 11		cabbage crop 12	
			at planting		at harvest		at harvest		at harvest		at harvest		at harvest	
			Structure Index	B / F	Structure Index	B / F	Structure Index	B / F	Structure Index	B / F	Structure Index	B / F	Structure Index	B / F
T1	High	Conventional[1]	23.83 b	0.336 a	11.22 a	0.570 a	30.61 a	0.656 ab	29.52 b	0.525 a	53.84 ab	0.554 b	66.08 a	0.694 a
T2	High	Compost[2]	21.44 b	0.479 a	10.54 a	0.444 a	41.80 a	0.748 ab	41.12 ab	0.567 a	73.31 a	0.750 a	52.86 a	0.616 a
T3	High	½ compost[3]	21.99 b	0.430 a	19.48 a	0.446 a	43.10 a	0.717 ab	45.82 ab	0.550 a	47.22 b	0.519 b	47.92 a	0.577 a
T4	Low	Conventional	23.25 b	0.503 a	9.73 a	0.507 a	16.78 a	0.636 ab	32.78 b	0.579 a	52.91 ab	0.649 ab	53.30 a	0.557 a
T5	Low	Compost	43.87 a	0.531 a	34.17 a	0.517 a	42.57 a	0.829 a	56.70 a	0.585 a	55.50 ab	0.671 ab	47.66 a	0.583 a
T6	Low	½ compost	26.69 ab	0.482 a	10.27 a	0.548 a	15.04 a	0.622 ab	35.28 ab	0.623 a	68.01 ab	0.681 ab	56.56 a	0.645 a
T7	Control	Control	22.49 b	0.298 a	12.83 a	0.451 a	38.47 a	0.557 b	31.18 b	0.631 a	61.45 ab	0.609 ab	47.84 a	0.585 a
		l.s.d. 5%	18.93	0.264	25.65	0.261	42.61	0.230	22.81	0.111	21.56	0.177	21.32	0.166

[1]conv = conventional practice (fertiliser and poultry manure)

[2]cGO = garden organic compost (125 dry t/ha)

[3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

B / F = Ratio of bacterivores to fungivores

c. Soil physical properties

The results for the percentage water stable aggregates in the soil are presented for crop 8 (lettuce) and crop 10 (sweet corn) following the 2nd application of compost, and crop 11 (capsicum) and crop 12 (cabbage) which followed the 3rd application of compost (Table 6-12).

The compost treatments (T2 and T5) resulted in a significantly ($P<0.05$) higher percentage of water stable soil aggregates in both the >2mm and the >250um size classes than the soil sampled from the conventional practice treatments (T1 and T4) for the lettuce crop (crop 8) which was the third crop following the 2nd compost application. However, by crop 10 (sweet corn), no significant difference was found in soil aggregate stability between the compost treatments and the conventional treatment soils. This illustrates that despite the compost improving soil physical structure after incorporation, intensive tillage of the soil using rotary hoes depletes those initial soil structural benefits over time.

The low P status mix treatment (1/2 compost rate) also achieved significantly ($P<0.05$) higher percentage water stable aggregates than the farmers practice for crop 8, but these were also significantly lower than the mean values for the full compost treatment. The same pattern of depletion of aggregate stability with time and tillage as was observed in the other treatments was also evident in the mix treatment results.

The results for the capsicum crop which was the first crop to follow the third application of compost, again demonstrated the benefits of the 125 dry t/ha compost application for rejuvenating soil structural stability, with the compost treatment soils having significantly ($P<0.05$) higher percentage of water stable aggregates than the conventional farming treatment soils. For this crop, no significant differences were found in the percentage of soil water stable aggregates between the mix treatment (62.5 dry t/ha CgO) and the conventional treatments, indicating that the lower rate of compost was insufficient to produce a significant benefit to soil structural stability on this occasion.

The soil water stable aggregate results for crop 12 (cabbage) reflects the soils response to the shortcomings of the previous capsicum crop. There was an extensive weed outbreak in the capsicum crop; after harvest the weeds were ploughed into the soil along with the crop residues. This input of additional organic matter from pasture weed species resulted in higher mean percentage water stable aggregate values for all treatments. The compost treatments (T2 and T5) again had significantly higher percentage water stable aggregates in their soils than the conventional treatments, with more than 42% of the soil as water stable aggregates > 250 um. These final results suggests the potential value of green manure crops and pasture leys for soil structure benefits in an intensive vegetable production system and prompted the sowing of an oat green manure crop (crop 12) after cabbage (crop 13).

Table 6-12: NSW DPI CROA vegetable field trial - Percentage water stable soil aggregates (>250 µm and >2 mm size) for crop 8 (lettuce) and 10 (sweet corn) which followed the 2nd compost application, and crop 11 (capsicum) and 12 (cabbage) which followed the 3rd compost application (different lower case letters indicate significant difference between treatment means at $P = 0.05$)

Treatment	Crop 8 - lettuce		Crop 10 – sweet corn		Crop 11 - capsicum		Crop 12 - cabbage	
	>250 µm	> 2mm	>250 µm	> 2mm	>250 µm	> 2mm	>250 µm	> 2mm
T1 – conventional[1] HP[4]	20.5 cd	4.2 cd	16.3	0.7	17.0 b	1.3 b	31.0 b	4.6 a
T2 – cGO[2] HP	36.7 a	9.8 a	19.9a	1.2	35.3 a	4.2 a	42.0 a	4.6 a
T3 – mix[3] HP	23.8 bc	5.0 bc	16.3	1.6	20.6 b	2.3 b	36.1 a	6.1 a
T4 – conventional LP[5]	19.0 d	3.5 cd	11.6	0.8	20.5 b	1.5 b	33.1 b	5.3 a
T5 – cGO LP	34.6 a	6.6 b	19.5a	1.2	34.0 a	4.9 a	43.2 a	6.8 a
T6 – mix LP	25.3 b	6.5 b	16.3	0.6	19.0 b	1.6 b	35.4 ab	6.6 a
T7 – control LP	11.8 e	2.6 d	11.4b	0.4	9.8 c	0.4 b	19.6 c	1.7 b
lsd (P=0.05)	4.2	2.3	6.3*		7.1	2.5	8.8	2.9

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha) / [3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous / [5]LP = low phosphorous

* P<0.05 for control vs treatments only - for crop 10 >250u data

d. Soil chemical properties

The soil chemistry soil quality parameters are presented in Table 6-13 for crop 8 (lettuce) and Table 6-14 for crop 10 (sweet corn), Table 6-15 for crop 11 (capsicum), and Table 6-16 for crop 12 (cabbage).

Tables 6-13 and 6-14 represent treatment effects on the soils in the 3rd and 5th crops following the 2nd application of compost. It is apparent in Table 6-13, that improvements to soil quality by the compost treatment are still evident even in the soil of third crop following the compost application.

Significant ($P<0.05$) improvements to many soil quality parameters including pH, Ca, total organic C (TOC), effective cation exchange capacity (eCEC), and some nutrient levels such as exchangeable K, and total N are apparent. A comparison of low soil P status cGO treatment (T5) versus the conventional practice (T4) treatment reveals the benefits of the compost to include an increase of 1 pH unit (5.98 vs 4.90), almost double organic C (2.25 vs 1.25), 50 percent improvement in the cation exchange capacity (10.75 vs 7.08), and much higher exchangeable K reserves (0.87 vs 0.53). It can also be seen that the mixed treatment (T6) which included a 62.5 dry t/ha compost application also significantly ($P<0.05$) improved these soil quality parameters relative to the conventional practice but typically achieved an intermediate improvement somewhere between conventional practice and the full compost treatment.

The soil chemistry results at the start of crop 10 (Table 6-14) reveal that although some soil quality benefits from the cGO treatment (e.g. TOC, eCEC) were still apparent (i.e. significantly different $P<0.05$), the extent of difference between the compost and conventional practice treatments had diminished somewhat with time as a consequence of carbon loss exacerbated by tillage and also the leaching of nutrients. It is apparent in the pH Ca results in Table 6-13 that the application of lime with dolomite prior to the sweet corn crop (crop 10) had restored soil pH levels to comparable values. However it is worth noting that the 1 pH unit difference between compost and conventional treatments required 3 t/ha of dolomite to ameliorate, which represents another economic benefit from compost.

The high levels of available Colwell P in the compost and mixed treatments (Tables 6-13 to 6-16) demonstrate that available P levels can build up in the soil with large applications of compost, as what happens with repeat applications of poultry manure under conventional practice. This indicates that available P needs to be a limiting factor when applying composts and other organic wastes like poultry manure. This means that the phosphorous content of compost should be used to determine the limit for compost applications to agricultural lands, based on the environmental risk that phosphorous poses to runoff and groundwater. These results help clarify and temper the initial perceived environmental benefits associated with soil P build up outlined in Chan et al. (2008, 2010). As such the continued application of composts and manures based solely on nitrogen fertiliser limits is probably unwise and such application rate limits need to take P loading into consideration in the context of soil available P levels and environmental risk.

The 3rd application of compost again had a significant impact on some soil quality parameters including total organic carbon (TOC) and effective cation exchange capacity (eCEC) which were double that of the conventional treatment soil values (Table 6-14). This application of compost, as with the previous ones in this trial, resulted in very large levels of plant available exchangeable K (i.e. 1.53 cmol (+)/kg),

but soil monitoring has found this to be mostly leached from the soil. As such, large applications of compost are not an efficient means of adding potassium to the soil, from a K fertiliser use efficiency perspective.

The only significant negative impacts of the compost treatment found in the field trial were an increase in soil salinity (EC) levels (0.40 vs 0.21) and soil sodicity (2.95% vs 1.7%). However this has been found to be confined to the first crop before it is leached out. Therefore it is not advisable to grow salt sensitive crops immediately following large compost applications (i.e. the first crop after application).

Table 6-13: NSW DPI CROA vegetable field trial - Soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 8 lettuce (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	EC	pHCa	TN	TOC	Exchangeable cations (cmol(+)/kg)					
	(dS/m)	($CaCl_2$)	(g/100 g)	(g/100 g)	eCEC	Al	Ca	K	Mg	Na
T1 – conventional[1] HP[4]	0.31 a	4.88 d	0.16 b	1.35 c	7.63 cd	0.06 a	5.35 c	0.54 c	1.43 b	0.25 a
T2 – cGO[2] HP	0.26 b	5.85 b	0.24 a	2.35 a	10.68 a	0.02 c	7.73 a	0.88 a	1.98 a	0.19 b
T3 – mix[3] HP	0.19 c	5.38 c	0.17 b	1.65 b	8.48 b	0.02 bc	6.35 b	0.61 b	1.35 b	0.15 b
T4 – conventional LP[5]	0.32 a	4.90 d	0.15 c	1.25 c	7.08 d	0.04 b	4.98 c	0.53 c	1.30 b	0.24 a
T5 – cGO LP	0.24 bc	5.98 a	0.24 a	2.25 a	10.75 a	0.02 c	7.50 a	0.87 a	1.90 a	0.17 b
T6 – mix LP	0.23 bc	5.35 c	0.18 b	1.63 b	8.05 bc	0.02 bc	6.00 b	0.55 c	1.33 b	0.18 b
T7 – control LP	0.11 d	4.88 d	0.11 d	1.02 d	5.58 e	0.05 a	4.15 d	0.19 d	1.01 c	0.16 b
Lsd (*P*=0.05)	0.06	0.12	0.02	0.16	0.59	0.01	0.44	0.05	0.15	0.04

Treatment	exch.Al	exch.Na	Colwell P		NH_4^+-N	NO_3^--N	
	(%)	(%)	Log	(mg/kg)	(mg/kg)	Log	(mg/kg)
T1 – conventional[1] HP[4]	0.80 a	3.25 a	2.55 a	354 a	14.5 a	2.09 a	123 a
T2 – cGO[2] HP	0.17 c	1.78 d	2.48 b	305 b	11.2 b	1.97 b	92 b
T3 – mix[3] HP	0.29 b	1.78 d	2.48 b	301 b	8.1 c	1.82 c	67 c
T4 – conventional LP[5]	0.51 b	3.33 a	2.43 c	267 c	14.0 a	2.12 a	131 a
T5 – cGO LP	0.15 c	1.55 d	2.27 d	187 d	10.4 b	1.92 bc	83 bc
T6 – mix LP	0.28 b	2.23 c	2.25 d	180 d	9.5b c	1.92 bc	84 bc
T7 – control LP	0.96 a	2.93 b	1.52 e	33 e	8.4 c	1.59 d	39 d
Lsd (*P*=0.05)	0.30	0.39	0.04		2.1	0.11	

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha) / [3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous / [5]LP = low phosphorous

Table 6-14: NSW DPI CROA vegetable field trial - soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 10 sweet corn (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	EC	pHCa	TN	TOC	Exchangeable cations (cmol(+)/kg)					
	(dS/m)	($CaCl_2$)	(g/100 g)	(g/100 g)	eCEC	Al	Ca	K	Mg	Na
T1 – conventional[1] HP[4]	0.63 ab	5.38 c	0.14 b	1.38 b	11.25 b	0.02 ab	7.40 b	0.83 a	2.45 ab	0.50 b
T2 – cGO[2] HP	0.59 bc	5.58 ab	0.18 a	2.18 a	14.00 a	0.01 ab	10.20 a	0.82 a	2.40 ab	0.41 b
T3 – mix[3] HP	0.57 bcd	5.48 bc	0.15 b	1.50 b	11.25 b	0.01 ab	8.50 b	0.55 b	1.98 cd	0.40 b
T4 – conventional LP[5]	0.71 a	5.53 abc	0.14 b	1.35 b	11.25 b	0.01 ab	7.48 b	0.86 a	2.60 a	0.61 a
T5 – cGO LP	0.47 d	5.70 a	0.19 a	2.15 a	13.75 a	0.01 b	10.03 a	0.81 a	2.28 bc	0.29 c
T6 – mix LP	0.50 cd	5.50 bc	0.16 b	1.53 b	10.75 b	0.01 ab	7.95 b	0.49 b	1.83 d	0.36 bc
T7 – control LP	0.28 e	5.58 ab	0.10 c	0.92 c	8.25 c	0.02 a	5.95 c	0.21 c	1.75 d	0.32 c
Lsd (*P*=0.05)	0.11	0.18	0.02	0.30	1.51	0.02	1.15	0.15	0.30	0.08

Treatment	exch.Al	exch.Na	Colwell P		NH_4^+-N	NO_3^--N
	(%)	(%)	Log	(mg/kg)	(mg/kg)	(mg/kg)
T1 – conventional[1] HP[4]	0.21 ab	4.55 a	2.62 a	419	17.8ab	235ab
T2 – cGO[2] HP	0.02 b	2.93 cd	2.47 c	297	7.7bc	230ab
T3 – mix[3] HP	0.08 ab	3.43 bc	2.51 bc	320	8.3bc	213b
T4 – conventional LP[5]	0.09 ab	5.30 a	2.55 b	358	22.3a	270a
T5 – cGO LP	0.02 b	2.15 d	2.27 d	185	5.9c	188b
T6 – mix LP	0.08 ab	3.38 bc	2.27 d	185	5.3c	185b
T7 – control LP	0.25 a	3.83 b	1.55 e	35	4.4c	100c
Lsd (*P*=0.05)	0.21	0.84	0.05		11.4	50

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha) / [3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous / [5]LP = low phosphorous

Table 6-15 NSW DPI CROA vegetable field trial - soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 11 capsicum (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	EC	pHCa	TN	TOC	Exchangeable cations (cmol(+)/kg)					
	(dS/m)	($CaCl_2$)	(g/100 g)	(g/100 g)	eCEC	Al	Ca	K	Mg	Na
T1 – conventional[1] HP[4]	0.16 b	5.53 d	0.13 c	1.30c	9.18 c	0.07 a	6.35 c	0.49 c	2.10 bc	0.15 c
T2 – cGO[2] HP	0.43 a	6.23 a	0.26 a	3.23 a	16.00 a	0.06 a	11.00 a	1.48 a	2.78 a	0.50 a
T3 – mix[3] HP	0.23 b	6.08 b	0.17 b	2.08 b	12.00 b	0.04 a	8.73 b	0.83 b	2.15 b	0.27 b
T4 – conventional LP[5]	0.21 b	5.53 d	0.13 c	1.25 c	8.45 d	0.02 b	5.78 cd	0.49 c	1.95 b	0.15 c
T5 – cGO LP	0.40 a	6.28 a	0.25 a	3.03 a	15.75 a	0.07 a	11.00 a	1.53 a	2.78 a	0.47 a
T6 – mix LP	0.24 b	6.03 b	0.16 bc	1.80 b	10.65 bc	0.03 b	7.63 b	0.77 b	2.03 bc	0.28 b
T7 – control LP	0.08 c	5.80 c	0.09 d	0.98 c	7.17 d	0.04 a	5.10 d	0.15 d	1.70 c	0.14 c
Lsd (*P*=0.05)	0.11	0.20	0.03	0.43	1.79	0.03	1.11	0.23	0.42	0.12

Treatment	exch.Al	exch.Na	Colwell P	NH_4^+-N	NO_3^--N
	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
T1 – conventional[1] HP[4]	1.18 ab	1.63 c	335 a	3.4 c	48 c
T2 – cGO[2] HP	0.34 c	3.08 a	330 a	7.3 a	124 a
T3 – mix[3] HP	0.54 bc	2.13 bc	280 b	4.9 b	55 c
T4 – conventional LP[5]	1.29 a	1.70 c	238 c	3.1 c	80 bc
T5 – cGO LP	0.45 c	2.95 a	240 c	6.9 a	103 ab
T6 – mix LP	0.48 c	2.50 ab	185 d	4.4 b	66 bc
T7 – control LP	0.66 abc	1.98 bc	40 e	2.0 d	19 d
Lsd (*P*=0.05)	0.67	0.69	38	0.8	39

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha) / [3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous / [5]LP = low phosphorous

Table 6-16 NSW DPI CROA vegetable field trial - soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 12 cabbage (different letters indicate a significant difference between treatments at P = 0.05)

Treatment	EC	pHCa	TN	TOC	Exchangeable cations (cmol(+)/kg)					
	(dS/m)	($CaCl_2$)	(g/100 g)	(g/100 g)	eCEC	Al	Ca	K	Mg	Na
T1 – conventional[1] HP[4]	0.20 bc	5.73 bc	0.19 ab	1.95 abc	11.2 bc	0.04	8.00 bc	0.85 bc	2.20 ab	0.20 ab
T2 – cGO[2] HP	0.17 cd	6.18 a	0.21 ab	2.48 ab	13.6 ab	0.05	9.98 ab	1.09 ab	2.20 ab	0.22 a
T3 – mix[3] HP	0.16 cd	5.98 ab	0.18 ab	2.10 abc	11.0 bc	0.03	8.43 bc	0.81 bc	1.85 bc	0.19 ab
T4 – conventional LP[5]	0.23 ab	5.53 c	0.16 bc	1.50 c	9.0 cd	0.05	6.28 cd	0.70 c	1.95 bc	0.21 ab
T5 – cGO LP	0.18 cd	6.25 a	0.23 a	2.68 a	15.0 a	0.04	11.00 a	1.25 a	2.30 a	0.19 ab
T6 – mix LP	0.15 d	5.95 ab	0.17 b	1.88 bcd	10.8 c	0.04	7.95 bc	0.79 bc	1.78 c	0.17 b
T7 – control LP	0.25 a	5.40 c	0.11 c	1.15 d	7.9 d	0.05	5.68 d	0.34 d	1.73 c	0.19 ab
Lsd (*P*=0.05)	0.04	0.34	0.05	0.73	2.7	NS	2.25	0.30	0.32	0.04

Treatment	Exch.Al	exch.Na	Colwell P	NH_4^+-N	NO_3^--N
	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
T1 – conventional[1] HP[4]	0.58	1.83	330 a	8.2	65 c
T2 – cGO[2] HP	0.38	1.70	293 b	4.0	48 d
T3 – mix[3] HP	0.40	1.60	263 d	4.1	39 d
T4 – conventional LP[5]	0.57	2.30	273 c	4.5	85 b
T5 – cGO LP	0.27	1.30	223 e	4.8	51 cd
T6 – mix LP	0.36	1.60	208 f	4.8	39 d
T7 – control LP	0.58	2.33	110 g	4.2	110 a
Lsd (*P*=0.05)	NS	NS	1.2	NS	15

[1]conventional = conventional farmer practice (fertiliser and poultry manure) / [2]cGO = garden organic compost (125 dry t/ha) / [3]mix = garden organic compost (62.5 dry t/ha) and fertiliser (½:½)

[4]HP = high phosphorous / [5]LP = low phosphorous

Benefit cost analyses

This work was funded by the Australian Centre for International Agricultural Research (ACIAR).

The cost benefit analysis of the compost vegetable trial for the full 10 crops (Orr and Eldridge 2012) revealed that both the full compost treatment and the mixed compost treatments compared favourably to conventional farmer practice on economic grounds. In this scenario, the full compost treatment (125 dry t/ha) and the mixed treatment (62.5 dry t/ha) compost applications were applied before crop 1 and then repeated before crop 6, with each application followed by 5 vegetable crops. The benefit cost analysis found that the compost treatment had a benefit cost ratio (BCR) of 3.33 compared to farmer practice, which translates into a $3.33 return for every $1 spent. The mixed treatment (62.5 dry t/ha) was also found to have a substantial Benefit Cost Ratio compared to farmer practice, with a BCR of 2.63. Most of the economic benefit from the compost and mix treatments compared to the farmer practice treatments related to the substantial yield benefits from the compost applications that were achieved in the high value capsicum crop (crop 6), the first vegetable crop following the repeat application of compost.

6.4. Discussion

The results of the vegetable field trial at CROA demonstrated that large applications of blended garden organic compost significantly improved soil quality (soil structure, chemistry, biology) and that these improvements diminished over time with aggressive rotary hoe tillage practices as consecutive crops were grown. The improvements in soil quality also led to production increases for all vegetable crops grown as the full compost treatment matched or exceeded the yield for the farmers practice treatment. However it was the response of the capsicum crop planted as the first crop following the application of compost that was most extraordinary (crop 6, results not reported). The full compost treatment (125 dry t/ha) capsicum crop achieved maximum potential yield for capsicum, which was almost double the farmer practice yield. The half compost treatment with half inorganic NPK fertiliser almost achieved similar yield results. The high value of the capsicum crop carried through to the economic analysis which found that the compost applications more than paid for their cost in this vegetable production system. Even under stressed conditions (poor watering, high weed pressure) the compost amended plots had higher yields than other treatments. As such, it is recommended that capsicum be the first crop following compost applications to maximise returns.

Analyses of the harvestable produce found significantly greater potassium levels in lettuces harvested from the compost and mixed treatments compared with farmer practice, which was also the case for the preceding crops 6 and 7. There was also significantly lower sodium contents in lettuces harvested from the compost and mixed treatments compared with conventional farmer practice. The K results were similar in the preceding crops 6 and 7. The lettuce (crop 8) results are consistent with the results of the crops following the first compost application in the field trial (Chan et al. 2008). The lack of a significant difference in K contents for crops 9 and 10 reflects the soil exchangeable K levels, which indicate a significant depletion, most likely due to leaching.

Soil quality results from crops 8-12 are generally in agreement with those from earlier crops grown in the field trial. Crop production removes carbon from the soil despite the return of residues with each crop. However, over time compost application has added carbon to the soil compared to farmers practice (Figure 6-5). The application of composted garden organics increased the ability of the soil to hold cations, reduced the rate of soil acidification and improved the buffering capacity of the soil compared to conventional farmer's practice. Lime was applied to all but the compost treatments after crop 9, illustrating an additional cost to the conventional vegetable production system.

There was a steady increase in phosphorous in the soil of the farmers practice treatments which was excess to crop requirements. Also, no phosphorous or potassium was added to the compost treatments after the second application of compost, and nitrogen (in the form of urea) was not applied until crops 9 and 10. The resultant build up in Available P (Colwell P) in the soil from the second application of compost which had slightly higher P content than the compost in the first application, demonstrated the reality that the P loadings from the compost and the soil available P levels need to be taken into account when determining suitable application rates. This is important to protect the environment. This also demonstrates that the continued application of composts at rates to provide available N to meet crop requirement for the first crop is not a sensible option in the long term as it will lead to the eventual build up of high P levels in the soil. However, the crop N requirement still provides a good maximum application rate for the initial compost applications to a vegetable soil. Likewise, larger applications of compost also result in a greater proportion of plant available K being lost to leaching, than might occur with smaller more regular applications. Thus to be able to utilise composts and other organic fertilisers effectively in vegetable production systems, we need to be able to have a reasonable prediction of the supply of plant available nutrients (at least NPK) from these materials as well as the available NPK reserves in the soil. This will allow applications of inorganic NPK fertiliser to be adjusted accordingly to ensure that the crop requirements are met in the right quantity at the right time, ensuring optimum yield or profit for the farmer and minimum adverse impact on the environment.

Compost also increased the percentage of water stable aggregates in the soil. This change leads to an increase in structural stability, aeration, drainage and creates a favourable environment for root growth.

Soil biology responses to the additional compost applications were more significant and prolonged compared to the responses measured in the initial application of compost at the start of the field trial. This suggested that more frequent applications of compost or larger inputs of compost and its organic carbon may be required for a sustained increase in soil biological activity relative to conventional practice. Other studies have shown that the addition of organic matter in the form of compost can lead to significant short-term changes in microbial biomass and activity in soil (Perez-Piqueres et al., 2006), with the effect generally diminishing over time as the compost decomposes. Perucci (1990) found the addition of municipal solid waste (MSW) immediately increased microbial biomass C for up to 1 month and Sanchez-Monedero et al., (2008) found that the addition of a range of organic amendments caused an initial large flush of CO_2 during the first 2 weeks of incubation before levels steadily decreased. However, in a longer term trial with multiple additions of MSW the increase in microbial biomass C over the control lasted for 8 years (Garcia-Gil et al.,

2000). Albiach et al., (2000) found a significant increase in enzymatic activities in response to MSW compost but although levels of microbial biomass were enhanced the effect was not statistically significant and the data was quite variable. Perucci (1992) found an increase in microbial biomass and enzyme activity in soil amended with municipal refuse and also found FDA hydrolysis to be a useful estimate of soil microbial activity.

Soil health indicators need to be able to quantify changes in soil properties so that improved land management practices can be identified and promoted (Pattison et al., 2008). Indicators should account for changes in soil quality (physical, chemical and biological properties) as well as crop productivity (Karlen et al., 2003). The composition and activity of soil microorganisms are potentially useful indicators of soil health because they are influenced by the chemical and physical properties of the soil (Alabouvette *et al*. 1996) which in turn are affected by management practices. Soil organisms also respond to management in time scales that are relevant to land managers (Pankhurst 1994). In particular soil dwelling nematodes have been found to be effective biological indicators of soil health due to their ability to respond to changes in the soil physical and chemical environment (Neher 2001; Pattison et al., 2008). However, biological results can be variable, and there does not appear to be one useful biological indicator for all situations (soil types, climates, crop types).

For example, compost application appeared to significantly increase numbers of predatory nematodes and reduce the population of plant parasitic nematodes in the soil but the results were not significant across all crops, nor did compost application appear to affect nematode diversity.

Another example is enzyme activity. Perucci (1992) studied the impact of municipal waste and found FDA hydrolysis to be a useful indicator of biological activity but our results were quite variable. FDA hydrolysis was found to be greater in compost amended soils, particularly in crop 11 straight after compost application which concurs with other biological indicators measured. However in crops 8 and 9 the opposite trend was observed and results across all crops were not consistent.

It is widely known that the application of organic amendments can impact on the incidence of soil-borne pathogens, although inconsistent results can affect their practical use in disease management (Bonanomi et al., 2010). The health status of the 12 crops grown in the field trial was assessed during crop growth and at harvest and no evidence of soil-borne disease was observed. Therefore the effect of the treatments on soil-borne disease, in particular the potential of composted garden organics to induce disease suppression was observed via pot trials using undisturbed soil cores taken from the field. This work has been reported in chapter 10.

The application of garden organic compost in this field trial significantly improved a number of other soil properties, including soil carbon, exchangeable cations and structural stability, compared with conventional farmers' practice (Chan et al., 2008). Yields for the compost treatments were similar or higher than in soils under conventional farmers' practice at both low and high P soil conditions (Chan et al., 2008; Chan et al., 2010; Chan et al., 2011). There were also significant savings in chemical fertilisers in the compost treatments (Chan et al., 2011). Other results of the field trial show that the high levels of extractable soil P currently found in vegetable farms around Sydney are not necessary for maintaining productivity. These high P levels are excessive and of environmental concern due to the off-site impacts

including potential for leaching and water pollution (Wells et al., 2000; Chan et al., 2007a; Chan et al., 2010).

The findings from this field trial have raised a number of additional research questions:

Does capsicum respond similarly to a first application of compost in a vegetable soil when it is the first crop? What rate is required to achieve this in certain soils?

Is much of the response of capsicum that was observed in this field trial related to the fact that it is a second application of compost, building on top of the initial large compost application?

What rate of compost as a second application is required to achieve maximum yield in capsicum and other crops?

Which soil quality parameters are dominant in the effect on capsicum?

Do any other Solanaceous vegetable crops also respond well to compost applications when grown as the first couple of crops following application?

Can minimum tillage or reduced tillage help prolong the positive effect of compost on soil quality compared to the high tillage conditions of the CROA field trial?

What is the best way to estimate the supply of plant available NPK from organic amendments such as compost, manure, blood and bone etc.?

What is the impact of large compost applications on soil quality and vegetable production at a site struggling to overcome significant soil-borne pest and disease issues?

What would be the economic benefit of large compost applications to vegetable crops grown in a permanent bed system, where the compost is only applied to the beds which reduces the cost per hectare?

6.5. Conclusion

The results of this study suggest that garden organic compost may be a useful soil conditioner to improve soils used for intensive vegetable production in the Sydney basin. The soil health and production results for the 12 crops grown to date in the long term field trial demonstrate there was no agronomic benefit to maintaining the soil at a high P status. This is important due to the off-site impact that excess P can have on the environment. The results also highlight the importance of maintaining long-term field trials which provide an opportunity to look at the influence of practice change on soil properties over time.

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7. South-east Queensland Field Trial

7.1. Summary

Farmers are required to adopt new cropping systems to continue to have cost effective and sustainable production. A project funded under the Caring for our Country program investigated the impact of a range of farming systems on runoff water quality. Farming systems were compared comprising vegetable and sugarcane rotations, with continuous vegetable production systems and a sugarcane farming system. The treatments followed the sugarcane crop cycles and included a sugarcane and vegetable rotation based on best practice or aspirational practices and a continuous vegetable production system. The difference between aspirational and best practice systems were based on nutrient management, tillage, trash or stubble management and herbicide application strategies. Initial sampling occurred at the beginning of the fallow period with follow-up samples during the cropping of capsicum, zucchini and pumpkin, respectively. The samples were processed for physical, chemical and biological soil characteristics. The Qld project team for VG09038 collaborated with the Caring for our Country project by testing soil samples for nematodes and other biological parameters. The soil was classified as loamy sand with high sand, low clay content, CEC and soil organic C. Nine variables were required as the minimum data set to separate the farming systems into the treatment groups; number of predatory and omnivorous nematodes, phosphorus buffering index (PBI), phosphorus (Colwell), Mn, labile C, fluorescein diacetate (FDA), enrichment index, Cu and Ca. There was a significant increase in the number of predatory and omnivorous nematodes over the under the Hort only A treatment relative to the two -- cane systems. The number of predatory and omnivorous nematodes appeared to be the most sensitive soil parameter to changes in the farming systems. The changes in soil biology over the course of the trial did not appear to be driven by changes in organic C.

7.2. Introduction

Farmers are forced to adopt new cropping systems in order to continue to have cost effective and sustainable production. Many of the new farming systems can be broadly grouped under conservation agriculture, which consists of three main principles; reduction in soil tillage, use of organic residues and diversification of cropping (Scopel *et al.* 2013). In a review of the impacts of conservation tillage in grain cropping systems Page *et al.* (2013) suggested there were physical, chemical and biological changes in the soil. They suggested there was an increase in water infiltration although soil bulk density tended to increase and porosity decreased. Chemically, there was a decrease in the pH of the soil, changes in the cation exchange capacity and availability of nutrients. There were also changes to the soil biology that were driven by changes in soil organic carbon. They also suggested that plant disease and weeds may increase under conservation agriculture (Page *et al.* 2013).

The development of more sustainable farming systems may increase the number of antagonistic organisms in the soil which potentially leads to the suppression of pathogens and increase sustainability (Bonanomi *et al.* 2010; Chaparro *et al.* 2012; Stone *et al.* 2004). However, further studies are needed to investigate the changes

that occur under conservation agricultural farming systems including the levels of suppression of soil borne diseases.

The Bundaberg region of Queensland predominantly produces sugarcane and horticulture crops. The value of the horticulture industry in the Burnett-Mary region has grown from $27.4M in 1980 to $453.9M in 2009 (Lovatt, pers. comm.), with more than 70% of that gross value derived from intensive vegetable production alone. A project funded under the Caring for our Country (http://www.nrm.gov.au/) program, through the Burnett-Mary Regional Group investigated the impact of a range of farming systems on runoff water quality. In the project, farming systems were compared comprising vegetable and sugarcane rotations, with continuous vegetable production systems and a sugarcane farming system, utilising fallow soybean cropping, reduced tillage and controlled traffic management (Nachimuthu *et al.* 2011).

To understand the changes in soil properties under vegetable production in different farming systems, the Qld DAFF project team for VG09038 conducted work in the existing 'Caring for our Country' trial in the Bundaberg region. VG09038 focused on investigating changes in the soil nematode community and other biological properties. It was hypothesised that the farming systems that incorporated the most organic -- matter, with minimal disturbance to the soil would increase soil biological activity and diversity, which could potentially suppress soil borne diseases. The focus of this component of the trial did not include yield and plant measurements as these were being reported by Nachimuthu *et al.* (2011).

7.3. Materials and methods

a. *Site description*

The trial was established in a 1.5 ha sugarcane site on a property south of Bundaberg. The soil type was classified as a Yellow/Brown Chromosol or a Yellow/Brown Dermosol, depending on the location within the field, but was reasonably uniform in the top 70cm. The site was split into 5 management units, with each unit being 280m long and 9m wide, with a 1.83m buffer strip between management units. The 280m length was divided into 2 subunits of approximately 120m and 160m, with drainage in either direction.

b. *Treatment description*

The experiment was conducted as a non replicated strip plot design. Each strip was assigned a different set of management practices in five different farming systems. Two treatments (a conventional sugarcane system and a new sugarcane farming system) were not used in this project because they did not include vegetables in their crop rotation plan. The studies in this project focused on the other treatments involving vegetable crops. The treatments followed the sugarcane crop cycles and included 1) a sugarcane and vegetable rotation based on best practice (Cane/Hort B); 2) a sugarcane and vegetable rotation based on aspirational practices (Cane/Hort A); and a continuous vegetable production systems where management was conducted using a mix of best and aspirational practices (Hort only A). The difference between aspirational and best practice systems were based on nutrient management, tillage, trash or stubble management and herbicide application strategies. Treatments were monitored for crop performance and profitability and published by Nachimuthu *et al*.

(2011). A comparative summary of the key features of each treatment is listed in Table 7-1, with a more detailed description provided below.

Cane/Hort B: The treatment had reduced nutrient application and used plastic mulch during the vegetable phase with the inter-rows sown to a cover crop (millet) managed as a living mulch to reduce sediment movement. Weed control utilised knock down herbicides only.

Cane/Hort A: The treatment utilized the existing sugarcane trash blanket rather than deploying plastic mulch or using inter-row mulch crops in the vegetable phase. A single pass of a ripper tine in the centre of the permanent cane bed was the only tillage event between the sugarcane and vegetable phases. The vegetables received a reduced rate of fertilizer compared to industry standard. Weeds were controlled in the vegetable phase with a combination of knock down herbicides and hand chip-hoe.

Hort only A: The continuous horticulture system was established with permanent beds formed and Rhodes grass (*Chloris gayana* cv. Katambora) established as a mulch crop to provide ground cover prior to capsicum planting. The mulch was subsequently sprayed out before planting, but organic mulch was established between vegetable crops to retain cover and enhance soil organic matter. Nutrient inputs were minimized, similar to the Cane/Hort A.

Table 7-1. A comparative summary of treatment characteristics

Treatment	Cane/Hort B	Cane/Hort A	Hort only A
Previous management	Cane	Cane	Rhodes Grass
Trash Management	Removed	Retained	Retained
Cultivation	Full Tillage	Strip	None
Plastic mulch	Yes	No	No
Fertilizer	Reduced	Reduced	Reduced
Inter-row crop	Yes (Jap millet)	No	No
First Crop	Capsicum	Capsicum	Capsicum
Fallow management	Forage sorghum slashed before planting zucchini	Forage sorghum slashed before planting zucchini	Forage sorghum slashed before planting zucchini
Second crop	Zucchini	Zucchini	Zucchini
Fallow	Forage Sorghum	Forage Sorghum	Forage Sorghum
Third crop	Pumpkin	Pumpkin	Pumpkin

c. *Sampling description*:

Initial sampling occurred in October 2010, at the beginning of the fallow period after the sugar cane had been harvested. Four separate sites within each plot were sampled and composed four sub-samples from the top 0-15 cm soil. Follow-up samples were conducted in January 2011, July 2011 and August 2012 during the cropping of capsicum, zucchini and pumpkin, respectively.

The samples were processed for physical, chemical and biological soil characteristics. Chemical analyses of soil were conducted using the Initec Pivot laboratories for

standard nutrient analysis as well as soil particle size analyses (OM, OC, pH, EC, NO_3, P, PBI, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, SO_4, sand, silt and clay)[2]. Biochemical analyses of soil samples were conducted at the DAFF Centre for Wet Tropics Agriculture and included soil enzymes, labile C and soil nematode community analysis (pH, EC, FDA, β-glucosidase, Labile C, nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators), diversity, enrichment, structure and channel indices).

Soil pH was determined in a 1:5 (soil:water) mix and measured using a pH multi probe. Labile carbon contents were determined by the amount of C oxidised by 33mM $KMnO_4$ in duplicate 5 g sub-samples using the method described by Moody and Cong (2008). Similarly, fluorescein diacetate (FDA) hydrolysis rate was determined from duplicate 5 g sub-samples using a modified version of the method initially proposed by Schnürer and Rosswall (1982). β-glucosidase was determined with the procedure published by Eivazi and Tabatabai (1988) except the toluene was substituted with 0.1% Tween solution and the modified universal buffer was replaced with a McIlvaine buffer (pH 6.0).

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g sub-sample of field moist soil was weighed onto a mesh sieve with a single ply of tissue and placed into a tray with 250 mL of water for 48 hours. The nematodes were collected on a 25 µm sieve and backwashed into a vial. The total number of nematodes was estimated and a 50 µL aliquot was placed on a glass slide. A minimum of 100 individual nematodes were identified to genus for plant-parasites and family for free-living nematodes.

Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators). Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index and the ratio of bacterivores and fungivores calculated (Yeates and Bongers 1999). Additionally, the weighted functional guilds analysis concept was applied, without plant parasites to determine the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris *et al.* 2001).

d. *Statistics*

A correlation analysis was performed on the data to remove variables that were derived from one another and highly correlated ($r > 0.80$). In these circumstances the variable that was measured, rather than derived indices, remained in the analysis. A second correlation analysis was performed to determine linear relationships between soil parameters. The uncorrelated means were used in a forward stepwise Discriminant Analysis (DA) to determine the minimum number of variables required to separate the treatments. The values obtained from composite samples across replicates were used for analysing soil nutrient data. A cross validation of the DA model was made using the leave-one-out (jack knife error) method.

[2] " Incitec Pivot Fertilisers - What is Nutrient Advantage?." Incitec Pivot Fertilisers - IPFHome. N.p., n.d. Web. 26 Mar. 2012. <http://www.incitecpivotfertilisers.com.au/en/Soil%20,-a-,%20Plant%20Tests/Nutrient%20Advantage.aspx>.

Polynomial regression analysis was used to determine the relationship between soil parameters over time and to determine if treatments could be separated having different time trends. All statistical analyses were conducted using Genstat 14 (VSN).

7.4. Results

a. Soil parameters

The mean values of the soil parameters measured are given in Table 7-2 for the soil chemical properties and Table 7-3 for soil nematode community and biochemical properties. The soil was classified as loamy sand having high sand and low clay content, with a low CEC and soil organic C throughout the trial (Table 7-2). There was greater than a five fold increase in the total number of nematodes extracted from the soil from the initial to the final sampling (Table 7-3). There was also a greater than 150 fold increase in the number of root knot nematodes (*Meloidogyne* sp.) over the course of the trial (Table 7-3).

The correlation analysis of the soil properties showed that the nematode trophic groups were related as changes in numbers affected each trophic group (Table 7-4). However, the numbers of fungivores and bacterivores were also related to biochemical changes in the soil FDA and labile C (Table 7-4). Organic C was unrelated to any of the changes in soil properties, which suggested changes in soil properties were not driven by changes of organic C (Table 7-4). However, the labile C fraction was correlated to β-glucosidase, CEC and Mg soil values (Table 7-4).

b. Treatments

The three farming system treatments, Cane/Hort A, Cane/Hort B and Hort only A, could be successfully separated from one another using a stepwise discriminate analysis (Figure 7-1). Nine variables were required as the minimum data set to separate the farming systems into the treatment groups; number of predatory and omnivorous nematodes, phosphorus buffering index (PBI), phosphorus (Colwell), Mn, labile C, fluorescein diacetate (FDA), enrichment index, Cu and Ca. The leave-one-out validation model suggested that using the nine soil parameters above it was possible to successfully assign an unknown treatment to the correct group 100 % of the time for each of the farming systems (data not shown).

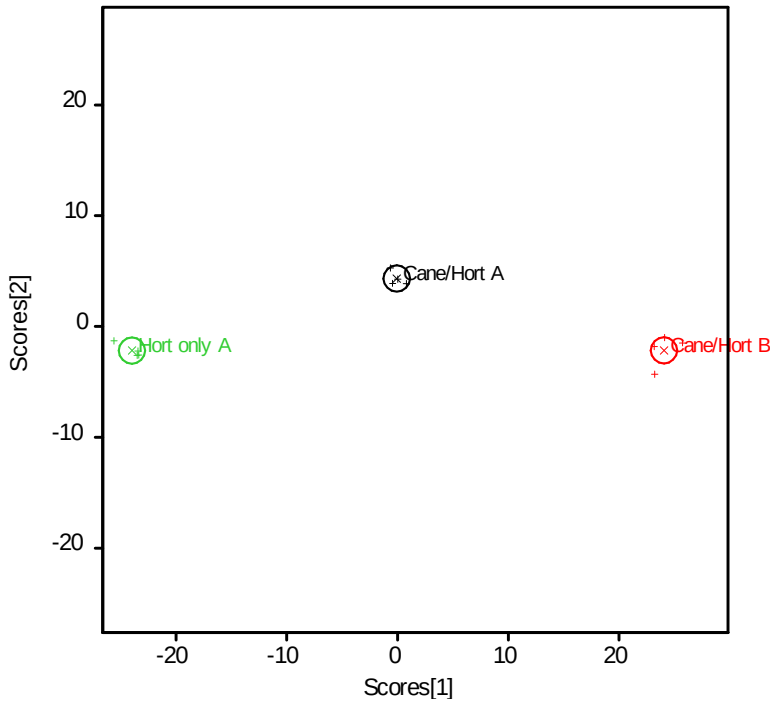

Figure 7-1: Discriminant analysis plot of farming system differentiation

A closer examination of the soil variables that were used to separate the farming systems was conducted using box plots (Figure 7-2). There was greater variation in the number of predatory and omnivorous nematodes in the Hort only A treatment relative to the Cane/Hort B and Cane/Hort A (Figure 7-2). The PBI showed the least variation in the Cane/Hort B system relative to the other two systems (Figure 7-2). The soil P tended to have greater values below the median in the Hort only A treatment than the two cane farming systems. The Cane/Hort B treatment tended to have lower Mn and greater labile C values relative to the Cane/Hort A and the Hort A only treatments (Figure 7-2). Cane/Hort A tended to have to lowest median FDA and the Hort only A treatment the greatest median, with the Cane/Hort B treatment having an intermediate FDA median value (Figure 7-2). Conversely, the Hort only A treatment had the lowest median enrichment index with the cane farming systems having similarly high median values (Figure 7-2). There was a similar trend for the amount of copper in the soil, with the Hort only A treatment having the lowest median value relative to the farming systems involving sugar cane (Figure 7-2). The Hort A only treatment had greater Ca values above the median relative to the two cane systems (Figure 7-2).

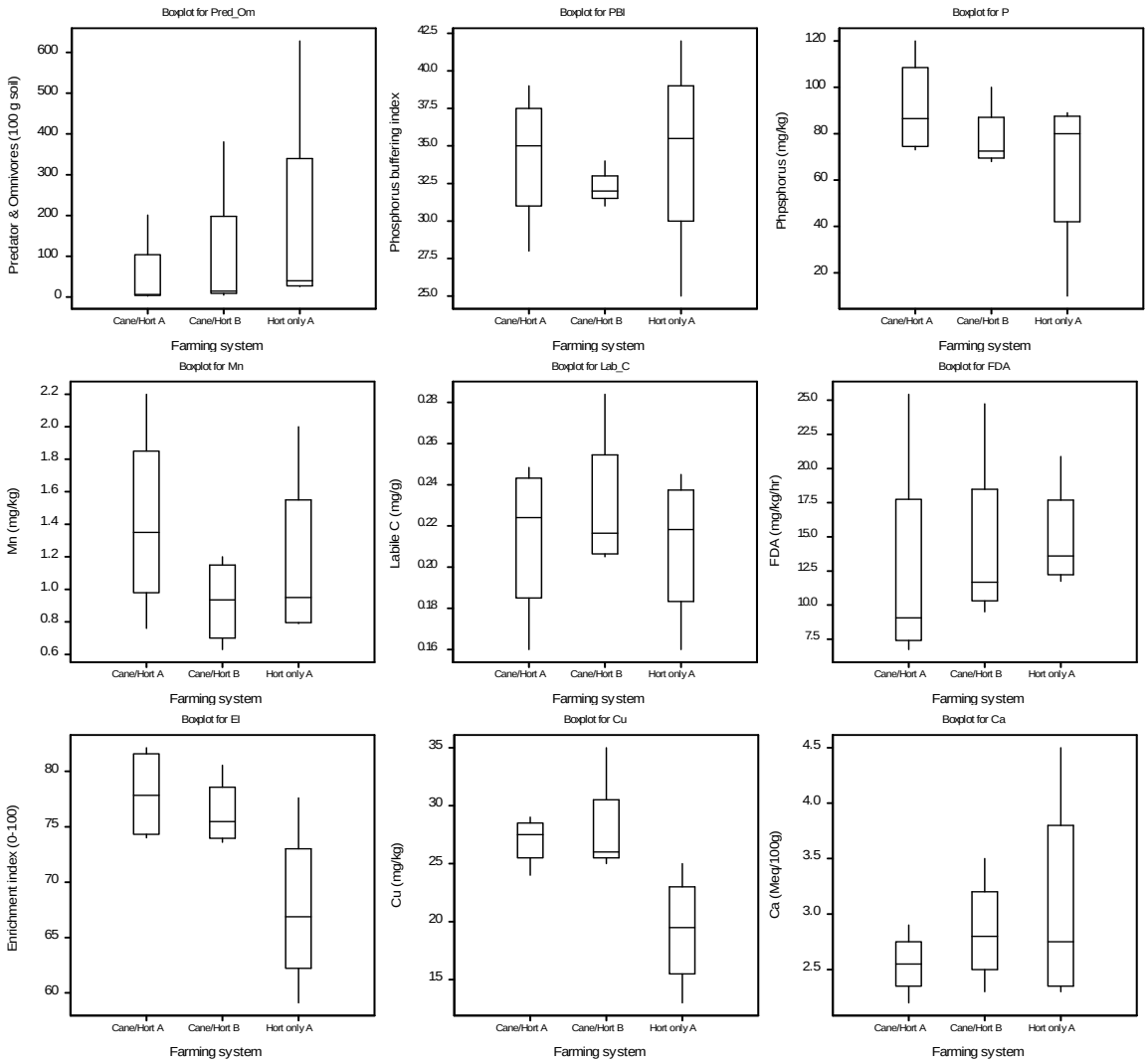

Figure 7-2: Box plots of soil properties, predator and omnivore nematodes, phosphorus buffering index (PBI), phosphorus (Colwell), Mn, labile C, fluorescein diacetate (FDA), enrichment index, Cu and Ca used to discriminate between the farming systems.

Table 7-2: Mean soil chemical properties at the Bundaberg trial site.

		Oct 2010		Jan 2011		Jul 2011		Aug 2012	
Sampling dates		**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**
Sand Coarse	%	30	± 2	32	± 2	26	± 4	35	± 2
Sand Fine	%	49	± 2	51	± 1	54	± 4	50	± 1
Silt	%	15	± 2	14	± 1	17	± 1	15	± 1
Clay	%	5	± 0	4	± 0	3	± 0	0	± 0
Organic Carbon	%	0.87	± 0.03	0.90	± 0.04	0.87	± 0.02	0.94	± 0.04
pH	(1:5 w)	6.80	± 0.15	6.40	± 0.06	6.43	± 0.32	6.87	± 0.15
Elect. Conductivity	dS/m	0.187	± 0.064	0.047	± 0.009	0.107	± 0.029	0.087	± 0.013
Chloride	mg/kg	12.0	± 2.0	10.0	± 0.0	10.0	± 0.0	13.0	± 1.7
Nitrate Nitrogen (NO_3)	mg/kg	37.3	± 11.8	7.7	± 2.8	34.0	± 7.5	25.0	± 5.5
Phosphorus (Colwell)	mg/kg	93.3	± 13.8	72.7	± 2.4	61.0	± 26.7	85.7	± 7.7
Phosphorus Buffer Index (PBI-Col)		35.3	± 2.3	36.0	± 3.1	35.0	± 0.6	28.3	± 2.0
Available Potassium	mg/kg	113	± 30	65	± 18	78	± 14	108	± 7
Cation Exch. Cap.	Meq/100g	3.31	± 0.13	3.27	± 0.16	3.91	± 0.81	4.30	± 0.25
Calcium (Amm-acet.)	Meq/100g	2.40	± 0.06	2.60	± 0.17	3.13	± 0.70	3.17	± 0.18
Potassium (Amm-acet.)	Meq/100g	0.29	± 0.08	0.17	± 0.05	0.20	± 0.04	0.28	± 0.02
Magnesium (Amm-acet.)	Meq/100g	0.58	± 0.07	0.47	± 0.05	0.53	± 0.10	0.82	± 0.09
Sodium (Amm-acet.)	Meq/100g	0.04	± 0.00	0.03	± 0.01	0.04	± 0.01	0.04	± 0.02
Copper (DTPA)	mg/kg	23.3	± 2.7	21.0	± 4.0	28.3	± 4.1	26.3	± 0.9
Iron (DTPA)	mg/kg	56.0	± 5.5	39.7	± 1.7	31.7	± 4.3	35.3	± 5.3
Manganese (DTPA)	mg/kg	0.78	± 0.01	0.98	± 0.18	1.80	± 0.31	1.13	± 0.21
Zinc (DTPA)	mg/kg	4.27	± 0.26	4.17	± 0.09	4.97	± 0.35	5.23	± 0.27
Sulfate Sulfur (MCP)	mg/kg	54.7	± 28.7	7.8	± 4.1	5.4	± 0.2	3.5	± 0.4

Table 7-3: Mean nematode trophic groups, nematode community indices and biochemical properties of soils at the Bundaberg trial site.

		Oct 2010		Jan 2011		Jul 2011		Aug 2012	
		Mean	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**
Total nematodes	100 g soil	563	± 100	1154	± 649	685	± 84	3294	± 528
Parasites	100 g soil	342	± 37	843	± 623	425	± 48	1621	± 247
Parasites	%	60	± 1	56	± 15	61	± 2	48	± 0
Pratylenchus sp	100 g soil	26	± 13	14	± 10	33	± 8	6	± 4
Meloidogyne sp.	100 g soil	7	± 2	612	± 603	93	± 64	1172	± 225
Fungivores	100 g soil	65	± 24	70	± 14	59	± 12	357	± 49
Fungivores	%	25	± 3	9	± 3	9	± 1	12	± 3
Bacterivores	100 g soil	141	± 39	228	± 20	178	± 31	912	± 178
Bacterivores	%	13	± 3	33	± 12	26	± 2	27	± 1
Predator & Omnivores	100 g soil	15	± 8	12	± 7	23	± 14	403	± 124
Predator & Omnivores	%	3	± 1	2	± 1	4	± 3	12	± 2
Taxa		9.6	± 0.4	10.2	± 0.6	10.5	± 0.0	9.3	± 0.5
B/(B+F) ratio		0.67	± 0.07	0.77	± 0.02	0.74	± 0.02	0.70	± 0.07
Diversity H'		1.65	± 0.07	1.48	± 0.21	1.76	± 0.03	1.83	± 0.03
Enrichment		72	± 3	71	± 6	77	± 4	75	± 1
Structure		21	± 7	22	± 6	32	± 11	64	± 6
Channel		31	± 4	16	± 5	15	± 3	17	± 4
Detrital		59	± 3	53	± 14	53	± 5	52	± 3
Predation		6	± 3	6	± 3	10	± 6	28	± 3
Roots		35	± 2	41	± 16	38	± 0	20	± 1
Labile C	mg g^{-1}	0.22	± 0.01	0.18	± 0.01	0.23	± 0.01	0.25	± 0.02
Fluorescein diacetate (FDA)	mg kg^{-1} hr^{-1}	11.34	± 0.66	11.23	± 1.86	9.65	± 1.72	23.69	± 1.42
β-glucosidase	µgPNG g^{-1} hr^{-1}	25.39	± 1.78	11.08	± 1.08	31.00	± 1.76	33.43	± 5.43

Table 7-4: Correlation (*r*) matrix of chemical, biochemical and nematode soil parameters at the Bundaberg trial site.

	B_G	Bact	CEC	CI	Ca	Chl	Cu	Div	EC	EI	FDA	Fe	Fung	K	L_C	Mg	Mn	NO3	Na	OC	P	PBI	Para	P Om	SI	SO4	Zn	pH
B_G	-																											
Bact	0.54	-																										
CEC	0.57	0.43	-																									
CI	-0.03	-0.36	-0.09	-																								
Ca	0.49	0.33	0.97*	-0.19	-																							
Chl	0.52	0.52	0.22	0.27	0.14	-																						
Cu	0.32	0.11	0.00	-0.46	-0.02	-0.22	-																					
Div	0.45	0.31	0.18	-0.12	0.06	0.07	0.24	-																				
EC	0.39	-0.21	0.18	0.67*	0.10	0.25	-0.09	-0.12	-																			
EI	0.21	0.12	-0.11	-0.63	-0.13	-0.24	0.85*	0.32	-0.21	-																		
FDA	0.36	0.81*	0.52	0.03	0.38	0.44	-0.05	0.31	-0.15	-0.21	-																	
Fe	-0.35	-0.44	-0.46	0.62	-0.58	-0.19	-0.02	-0.22	0.48	-0.02	-0.23	-																
Fung	0.45	0.85*	0.51	-0.08	0.37	0.58	0.10	0.31	-0.14	-0.04	0.95*	-0.30	-															
K	0.34	0.12	0.31	0.60	0.12	0.25	-0.18	0.21	0.75*	-0.31	0.34	0.39	0.29	-														
L_C	0.79*	0.45	0.68*	0.11	0.56	0.39	0.43	0.21	0.44	0.15	0.53	-0.08	0.60	0.52	-													
Mg	0.58	0.68*	0.74*	-0.09	0.57	0.42	0.09	0.44	0.06	0.14	0.71*	-0.18	0.73*	0.39	0.69*	-												
Mn	0.21	-0.19	0.28	-0.22	0.31	-0.29	0.13	0.45	-0.11	0.15	-0.11	-0.41	-0.06	-0.01	0.09	0.05	-											
NO3	0.66*	-0.05	0.25	0.47	0.18	0.37	0.01	0.06	0.88*	-0.09	-0.10	0.18	-0.03	0.63	0.55	0.14	0.20	-										
Na	-0.05	-0.20	-0.15	0.25	-0.19	-0.29	0.41	0.11	0.03	0.18	0.13	0.40	0.10	0.04	0.18	-0.12	0.26	0.05	-									
OC	-0.19	0.29	0.03	-0.02	-0.07	-0.14	0.09	0.09	-0.43	-0.15	0.62	0.05	0.53	0.11	0.19	0.24	0.00	-0.43	0.36	-								
P	-0.09	0.09	-0.57	0.18	-0.67*	0.05	0.37	0.08	0.18	0.26	0.06	0.55	0.10	0.27	0.01	-0.22	-0.49	0.02	0.29	0.16	-							
PBI	-0.41	-0.72*	-0.33	0.44	-0.28	-0.18	-0.42	-0.29	0.33	-0.48	-0.56	0.24	-0.58	0.26	-0.35	-0.56	0.13	0.21	-0.21	-0.14	-0.04	-						
Para	0.29	0.77*	0.35	-0.39	0.32	0.36	0.20	-0.29	-0.23	0.11	0.61	-0.29	0.68*	-0.12	0.42	0.44	-0.33	-0.13	-0.04	0.33	0.02	-0.66*	-					
P Om	0.61	0.98*	0.45	-0.30	0.35	0.51	0.06	0.36	-0.08	0.10	0.76*	-0.40	0.78*	0.21	0.46	0.68*	-0.16	0.08	-0.23	0.17	0.08	-0.69*	0.69*	-				
SI	0.63	0.83*	0.68*	-0.14	0.61	0.49	-0.13	0.47	-0.10	-0.18	0.81*	-0.59	0.78*	0.22	0.47	0.68*	0.15	0.10	-0.14	0.18	-0.25	-0.56	0.48	0.85*	-			
SO4	0.01	-0.35	-0.15	0.62	-0.24	0.01	0.01	-0.28	0.86*	-0.08	-0.27	0.77*	-0.28	0.65*	0.21	-0.14	-0.38	0.58	0.09	-0.27	0.50	0.40	-0.25	-0.26	-0.44	-		
Zn	0.54	0.45	0.44	-0.33	0.35	-0.15	0.39	0.47	0.04	0.40	0.39	-0.19	0.40	0.25	0.49	0.49	0.55	0.29	0.37	0.18	-0.08	-0.51	0.31	0.52	0.50	-0.16	-	
pH	0.53	0.43	0.63	0.35	0.53	0.50	-0.23	0.14	0.56	-0.30	0.46	-0.02	0.40	0.58	0.51	0.55	-0.34	0.42	-0.29	-0.25	-0.01	-0.23	0.19	0.52	0.57	0.36	0.07	-
taxa	-0.30	-0.43	-0.14	-0.39	0.03	-0.51	0.32	-0.19	-0.43	0.38	-0.47	-0.14	-0.44	-0.78*	-0.34	-0.39	0.33	-0.35	0.38	-0.20	-0.35	-0.19	-0.10	-0.48	-0.36	-0.39	0.01	-0.56

* denotes significant correlation ($P<0.05$). B_G = β-glucosidase; Bact = Bacterivores; CEC = Cation exchange capacity; CI = Channel Index; Ca = Calcium; Chl = Chlorine; Cu = Copper; Div = Nematode diversity; EC = Electrical conductivity; EI = Enrichment index; FDA = Fluorescein diacetate; Fe = Iron; Fung = Fungivores; K = Potassium; L_C = Labile C; Mg = Magnesium; Mn = Manganese; NO3 = Nitrate nitrogen; OC = Organic carbon; P = Phosphorus; PBI = Phosphorus buffering index; Para = Plant-parasitic nematodes; P Om = Predatory and omnivorous nematodes; SI = Structure index; SO4 = Sulphate; Zn = Zinc; pH = pH(1:5 water); taxa = Number of nematode taxa identified.

c. Treatment and time interactions

Regression analysis to determine the interactions between the farming system treatments over the 22 months of monitoring of the trial suggested that only one parameter, the number of predatory and omnivorous nematodes in 100 g of soil experienced significant independent changes over time for the three farming systems, which could explain 99% of their variation (Table 7-5, Figure 7-3). There was a significant increase in the number of predatory and omnivorous nematodes under the Hort only A treatment relative to the two cane systems (Figure 7-3). Furthermore, there was a significant increase in the number of predatory and omnivorous nematodes under the Cane/Hort B systems relative to the Cane /Hort A system (Figure 7-3).

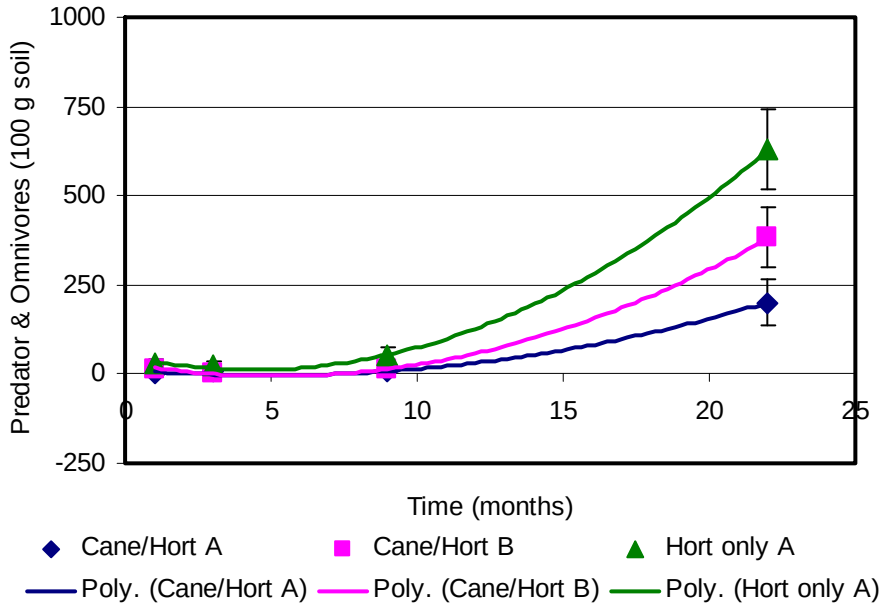

Figure 7-3: Treatment effects on the number of predatory and omnivorous nematodes

Furthermore, there were significant treatment effects over time for the nematode community structure index and the amount of Cu in the soil (Table 7-5). However, the three treatments did not behave independently over time and followed a similar time trend; parallel curves, with differing constants (Table 7-5). In the analysis of structure index over the course of the trial, the Hort only A treatment had a significantly greater constant, 32.93, relative to the two farming systems involving sugarcane, which suggested greater structure indices throughout the monitoring of the trial (Table 7-5). Conversely, in the analysis of the Cu levels, the Hort only A treatment had a significantly lower constant value for the polynomial regression relative to the two cane farming systems (Table 7-5).

The soil parameters; number of fungivorous and bacterivorous nematodes, the FDA and Mn levels in the soil all had a significant time trend that could be explained with a quadratic equation (Table 7-5). However, there were no significant treatment differences, which suggested seasonal or time influences. The FDA, number of bacterivores and fungivores all tended to increase with time over the course of the

experiment, where as the amount of Mn in the soil peaked mid way through the trial in the zucchini crop and then decreased (Table 7-5).

Table 7-5: Treatment and time interactions of soil parameters under different farming systems.

Treatment x Time effect	Parameter	Equation	R^2
Quadratic independent treatment effects	Predators and omnivores (100 g soil)	Hort only A = $1.986x^2 - 17.46x + 50.72$ Cane/Hort A = $0.7x^2 - 6.894x + 13.53$ Cane/Hort B = $1.357x^2 - 13.944x + 30.40$	0.99 ***
Quadratic parallel treatment effects	Structure index	Hort only A = $0.0444x^2 + 1.048x + 32.93$ Cane/Hort A = $0.0444x^2 + 1.048x + 10.05$ Cane/Hort B = $0.0444x^2 + 1.048x + 14.11$	0.93 ***
	Cu	Hort only A = $-0.038x^2 + 1.104x + 15.05$ Cane/Hort A = $-0.038x^2 + 1.104x + 22.8$ Cane/Hort B = $-0.038x^2 + 1.104x + 23.8$	0.57 *
Quadratic time effects	Fungivores (100 g soil)	$y = 1.1339x^2 - 12.595x + 85.001$	0.88 ***
	FDA	$y = 0.0617x^2 - 0.8536x + 12.577$	0.84 ***
	Bacterivores (100 g soil)	$y = 2.4934x^2 - 22.943x + 207.09$	0.80 ***
	Mn	$y = -0.0086x^2 + 0.2176x + 0.50$	0.54 *

*, ** and *** denotes significant regression coefficient with $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively

7.5. Discussion

The number of predatory and omnivorous nematodes appeared to be the most sensitive soil parameter to changes in the farming systems. There were greater numbers of predatory and omnivorous nematodes under the Hort only A treatment, which had a Rhodes grass fallow at the beginning of the experiment. It appeared this type of fallow favoured a more structured soil food web, having a greater structure index throughout the experiment under the different vegetable crops. The soil food web structure is determined partly from the number of predatory and omnivorous nematodes. The predatory and omnivorous nematodes and the soil food web are sensitive to disturbances and it is possible under the cane systems that there was greater disturbance of the soil biology. The numbers of predatory and omnivorous nematodes also indicate the potential for regulation of parasitic organisms by top down predators. This suggested that there was a greater potential for suppression in the Hort only A treatment, although this was not confirmed by the presence of root-knot nematodes.

The changes in soil biology over the course of the trial did not appear to be driven by changes in organic C. There were very few changes in soil properties over time under the different farming systems. Although there was greater soil organic C and labile C at the end of the trial relative to the beginning, the changes appeared to be inadequate for creating lasting changes that could bring about suppression of soil borne pathogens like root-knot nematode. However, there was an increase in biological activity, determined by FDA analysis, at the trial site which suggested that soil biology was initially low and increased over the course of the experiment. There was

also a weak correlation between the labile C and the CEC, which suggested that, there was greater potential for the soil to retain cations as labile C increased.

The trial site was a sandy loam soil that had a low CEC and initially low organic C. The high sand content of the soil, approximately 80%, may have constrained the ability of management practices to increase organic C and change soil biological characteristics. Soils with a high sand content tend to be unable to protect organic matter from decomposition by soil microorganisms making it difficult to sequester carbon in agriculture production. The sandy texture of the soil may have had a greater influence on the biological properties of the soil than the soil organic C changes. It is likely that the trial site required more time and organic matter inputs to create a long term effect on the soil biology.

The increase in soil nematodes as the trial progressed may have been in response to an increase in resources for the soil nematode community, either organic matter or roots. The continual cropping of vegetables (capsicum, zucchini and pumpkin) in 22 months meant that there were roots that could potentially host nematodes throughout the trial. In the final crop, pumpkin, there was a large increase in the number of root-knot nematode in all treatments, with no treatment effects. This suggested that even though there tended to be an increase in biological activity and complexity of the soil food web as the trial progressed, it was not enough to prevent root-knot nematode from increasing and that other factors such as crop management and crop type played a greater role in the development of the pathogen numbers. The number of plant-parasitic nematodes was independent of the soil factors measured in this trial.
The ability to separate the farming system treatments using a stepwise discriminate analysis suggested that management has a significant impact on soil properties over time. The three farming systems investigated had separate soil characteristics, a combination of chemical, biochemical and soil biological measurements. However, there was variability around the measurements which showed there was also overlap in the soil properties between the three farming systems. The soil properties used to discriminate between the farming systems appeared to be due to crop management inputs, such as fertiliser and pesticides.

The chemical soil properties P, PBI and Mn all tended to have a lower median value in the Cane/hort B treatment than the other two systems. This may have been due to slight variations in soil type across the trial site. However, the Cu value tended to have a lower median value in the Hort only A treatment, which suggested that sugar cane may have Cu containing agrichemicals applied to the soil.

Nachimuthu *et al*. (2011) found greater yields and profitability in the conventional production systems relative to the best bet and aspirational farming systems. They found that capsicum yields in the Cane/Hort B treatment were 80% of the yield of the conventional vegetable production, which was not included in this study, with yields in the Cane/Hort A treatment only 45% of the conventional treatment (Nachimuthu *et al*. 2011). However, further studies on the apparent nutrient use efficiency suggested that the conventional system was least nutrient efficient system for N, P and K (Nachimuthu *et al*. 2011). The nutrient efficiency of the Cane/Hort A and B treatments were similar. However, there was greater nutrient export in the conventional treatment relative to the Cane/Hort B treatment, which was greater than the Cane/Hort A treatment (Nachimuthu *et al*. 2011).

7.6. Conclusion

Changes in the number of predatory and omnivorous nematodes and their contribution to the soil food web structure occurred over time under the three different farming systems (Hort only A, Cane/Hort A and Cane/Hort B) and suggests a greater potential for soil pathogen suppression. The greatest increase occurred under the Hort only A treatment, which had Rhodes grass as a fallow crop instead of sugar cane. However, changes in other soil properties and suppression of plant-plant parasitic nematodes under the different tillage treatments did not occur. There were indications of increased biological activity occurring with continuous cultivation of vegetables. This may be in part due to the fallow crop grown in between vegetable crops to allow organic mulch to be produced with the aspiration treatments. Further development of the aspirational treatments is necessary if vegetable production practices are to develop that do not need plastic mulch for weed suppression or water retention and if they are to produce comparable yields and quality to current vegetable production systems.

7.7. References

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8. Commercial farm trial – north Queensland

8.1. Summary

Cost effective and sustainable vegetable production is an essential goal for farmers, driving the adoption of new cropping systems, such as conservation agriculture. A study was initiated to determine if renovation of semi-permanent beds by periodic tillage had a negative effect on ecological soil parameters. A commercial farm which had developed minimum tillage systems for their zucchini production, had three fields selected, with different ages since the beds had been tilled and reformed, 5, 3 and 0 years before. At each site, a uniform block of 1 ha was chosen and divided into 4 sampling areas, for physical, chemical and biological measurements. A composite sample for nutrients, soil enzyme activity and soil nematode community structure was taken from each site. Organic C levels throughout the trial ranged from 1.5 to 1.9 %, and were considered relatively high compared to vegetable production systems in the Bowen / Burdekin region. Soil organic C in the minimum tillage system tended to follow a seasonal trend depending on the cropping phase, either fallow or cropped, with the labile C component driving many of the biological processes, particularly enzymatic soil functions. Increased labile C helped alleviate soil compaction in the top 15 cm of soil, with a critical labile C value of 0.50 mg/g, where soil compaction was greatly reduced. The reduction in soil compaction was further associated with lower numbers of the plant-parasitic nematode *Rotylenchulus reniformis*. The renovation of the beds appeared to have only a temporary effect on soil biology, improving the overall soil health parameters under a minimum tillage system. An increase in soil organic C may have given vegetables greater resilience and the ability to recover from the disturbance.

8.2. Introduction

Cost effective and sustainable vegetable production is an essential goal for farmers, driving the adoption of new cropping systems, such as conservation agriculture. Many of the new farming systems can be broadly grouped under conservation agriculture, which consists of three main principles; reduction in soil tillage, use of organic residues and diversification of cropping (Scopel *et al.* 2013). In a review of the impacts of conservation tillage in grain cropping systems, Page *et al.* (2013) suggested there were physical, chemical and biological changes in the soil. They suggested there was an increase in water infiltration, although soil bulk density tended to increase and porosity decreased. Chemically, there was a decrease in the pH of the soil, changes in the cation exchange capacity and availability of nutrients. There were also changes to the soil biology that were driven by changes in soil organic carbon (Fageria 2012; Huang *et al.* 2013).

Soil organic matter has been described as a reactive and dynamic component of the soils, which is associated with the soils productive characteristics (Fageria 2012). Turnover of soil organic matter represents energy (carbon, C) and nutrient flows of a soil and is closely related to inherent soil properties (Fageria 2012). Improving soil organic C content is difficult in farming soils because of the rapid decomposition of organic matter and the heterogeneous nature of soils and organic matter (Fageria 2012).

The development of more sustainable farming systems may increase the number of antagonistic organisms in the soil which potentially leads to the suppression of pathogens and increases sustainability (Bonanomi *et al.* 2010; Chaparro *et al.* 2012; Stone *et al.* 2004). However, there is still a need for further work investigating the changes that occur under conservation agricultural farming systems including levels of suppression of soil borne diseases.

Vegetables grown in the warm Burdekin Dry Tropics are an important supply for winter markets in the southern metropolitan areas of Australia. Land preparation includes multiple annual tillage operations; planting beds covered with polyethylene mulch; drip irrigation; and no summer cover crops or additional organic matter inputs in conventional production systems. Soil organic carbon (SOC) levels of 0.5% are common with conventional tillage. It is anticipated that an increase in SOC will improve soil health and crop productivity in the long term. SOC of up to 1.7% has been measured in a less common and more sustainable farming system with zucchini in the Burdekin area. This farming system includes minimum tillage with semi-permanent beds, controlled traffic farming, subsurface drip irrigation, and slashed forage sorghum as bed mulch (grown during the wet season to reduce soil erosion and add organic matter). Cultivation and reforming of the beds occurs every five years on average, depending on the integrities of planting beds (which decrease in height with time) and drip irrigation lines (which can be damaged by birds, rodents, feral animals and planting machinery). A pictorial description of the sequence of farming practices in the zucchini crops is presented in Figure 8-1. The aim of this study was to determine if periodic renovation had a negative effect on ecological soil parameters in a vegetable production system.

8.3. Materials and methods

Site description

A commercial farm which had developed minimum tillage systems for their zucchini production over a 10 year period was selected for this study. Three adjacent fields, on the same Andisol soil type, with different ages since beds had been last tilled and reformed were selected as study sites (Table 8-1). When the monitoring of soil properties began, the renovation of the fields had occurred 5, 3 and 0 years before (2005, 2008 and 2010 respectively) (Table 8-1). The trial was conducted as a non-replicated design with sub-samples.

Table 8-1: Location and physical characteristics of field monitoring sites

Site	Irrigation Valve 3 (V3)	Irrigation Valve 5 (V5)	Irrigation Valve 10/11 (V10/11)
Year renovated	**2008**	**2005**	**2010**
Latitude	19° 29.753’	19° 29.872’	19° 30.100’
Longitude	147° 07.237’	147° 07.115’	147° 06.951’
Elevation (masl)	0	8	15
Sand (coarse) (%)	3 ± 0.8	1 ± 0.2	1 ± 0.3
Sand (fine) (%)	44 ± 1.1	47 ± 1.8	49 ± 25
Silt (%)	26 ± 0.6	24 ± 1.6	22 ± 2.2
Clay (%)	27 ± 0.4	29 ± 0.4	27 ± 0.6

Figure 8-1: Year one in a 5-year semi-permanent bed system with sorghum as summer cover crop commencing at the end of the dry season and grown through the wet season (1-5) and zucchini grown over the dry season (6-9), before replanting to forage sorghum at the end of the dry season (10).

Sampling description
At each site, a uniform block of 1 ha was chosen, located with the use of GPS, and divided into 4 sampling areas, each with approximately 0.25 ha. From each sampling area, 20 soil cores were randomly collected using a 5 cm diameter auger to a depth of 10 cm. The soil cores were used to form a composite sample for chemical and biological measurements. Samples for biochemical measurements were immediately placed in a foam box with ice. Samples for nematode analysis were kept out of the sun and cooled, but not refrigerated. Samples for chemical analysis were refrigerated overnight before being sent to a commercial laboratory.

Initial sampling occurred in October 2010, which corresponded with the beginning of the fallow period after the zucchini had been harvested. Follow up samples were conducted in May 2011, at planting of zucchini, August 2011 at harvest of zucchini, December 2011 during the fallow, July 2012 during the zucchini crop and again in February 2013 during the fallow.

Physical soil properties measured included soil penetration resistance and bulk density. Soil resistance was measured using a push penetrometer (Dickey John), with a 3 cm^2 cone. Resistance readings were determined for 0-15, 15-30 and 30-45 cm intervals. In each 0.25 ha sampling area, 10 recordings to 45 cm depth were made, totalling 40 readings per site. Soil bulk density was determined using the procedure described by Arshad *et al.* (1996). Aluminium tubes, 7.5 cm diameter x 10 cm long and of known weight, were driven into the soil until the ends were level with the soil surface. The wet weight of the soil and tubes was determined before being placed in an oven for three days at 105° C and then reweighed. Soil moisture characteristics such as gravimetric water and water filled pore space (WFPS) were also determined (Arshad *et al.* 1996). Three tubes were used per 0.25 ha sampling area totalling 12 readings per site.

Chemical analysis of soils was conducted using the Incitec Pivot laboratories for standard nutrient analysis as well as soil particle size analysis (OM, OC, pH, EC, NO_3, P, PBI, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, SO_4, sand, silt and clay)[3]. Biochemical analysis of soil samples were conducted at the DAFF Centre for Wet Tropics Agriculture and included soil enzymes, labile C and soil nematode community analysis (pH, EC, FDA, β-glucosidase, Labile C, nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators), diversity, enrichment, structure and channel indices).

Labile carbon contents were determined by the amount of C oxidised by 33mM $KMnO_4$ in duplicate 5 g sub-samples using the method described by Moody and Cong (2008). Similarly, fluorescein diacetate (FDA) hydrolysis rate was determined from duplicate 5 g sub-samples using a modified version of the method initially proposed by Schnürer and Rosswall (1982). β-glucosidase was determined with the procedure published by Eivazi and Tabatabai (1988) except the toluene was substituted with

[3] " Incitec Pivot Fertilisers - What is Nutrient Advantage?." Incitec Pivot Fertilisers - IPFHome. N.p., n.d. Web. 26 Mar. 2012. <http://www.incitecpivotfertilisers.com.au/en/Soil%20,-a-,%20Plant%20Tests/Nutrient%20Advantage.aspx>.

0.1% Tween solution and the modified universal buffer was replaced with a McIlvaine buffer (pH 6.0).

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g of field moist sub-sample was weighed onto a mesh sieve with a single ply of tissue and placed into a tray with 250 mL of water for 48 hours. The nematodes were collected on a 25 µm sieve and backwashed into a vial. The total number of nematodes was estimated and a 50 µL aliquot was placed on a glass slide. A minimum of 100 individual nematodes were identified to genus for plant-parasites and family for free-living nematodes.

Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators). Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index and the ratio of bacterivores and fungivores was calculated (Yeates and Bongers 1999). Additionally, the weighted functional guilds analysis concept was applied, without plant parasites to determine the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris *et al.* 2001).

Statistics
All data was analysed for differences between fields and trends in time using valid statistical procedures. Firstly, a correlation analysis was performed on the data to remove variables that were derived from one another which were highly correlated ($r > 0.80$). In these circumstances the variable that was measured, rather than derived indices, remained in the analysis. A second correlation analysis was performed to determine linear relationships between soil parameters. The uncorrelated means were used in a forward stepwise Discriminant Analysis (DA) to determine the minimum number of variables required to separate the treatments. For soil nutrient analysis data the values obtained from composite samples across replicates was used. Cross validation of the DA model was made using the leave-one-out (jack knife error) method. Polynomial regression analysis was used to determine the relationship between soil parameters over time and to determine if treatments could be separated over time. All statistical analyses were conducted using GenStat for Windows 14th Edition (VSN International 2011).

8.4. Results

Soil parameters
Means for soil chemical and physical properties at each sampling time are given in Table 8-2. Organic C levels throughout the trial ranged from 1.5 to 1.9 %, and were considered relatively high compared to vegetable production systems in the Bowen / Burdekin region (commonly in the range of 0.5 and 1%) (Table 8-2). The levels of the major nutrients are also given Table 7-2, for the different phases in the cropping cycles. Wet weather from typical monsoonal rains during the 2012-13 summer led to very high values of water filled pore space (WFPS) at 97% and soil saturation conditions in the February 2013 soil sampling (Table 8-2). The penetrometer results down the soil profile are given in Figure 8-2. The penetrometer results indicated that resistance to soil penetration increased down the soil profile (Figure 8-2). The

penetration resistance tended to be lower in V10/11 (Irrigation Valve 10/11) relative to the other fields, especially during the fallow period (Figure 8-2).

The means for biochemical and nematode analysis are given in Table 8-3. The nematode community was typically composed of 37% plant-parasitic nematodes, 27% fungivores, 23% bacterivores and 13% predators and omnivores (Table 8-3). The diversity of nematodes remained around 2.00, with the enrichment, structure and channel indices around 50 (Table 8-3).

The correlation between soil parameters is given in Table 8-4. Many of the nematode indices were related, which suggested that when nematode numbers increased, this increase occurred across all trophic groups (Table 8-4). Similarly, many of the nutrient parameters were related to electrical conductivity, which would be expected as the nutrients are applied as salts (Table 8-4). There were significant correlations between penetration resistance in the top 15 cm and a number of biological parameters such as labile C, FDA, number of bacterivores and number of *Rotylenchulus reniformis* (Table 8-4).

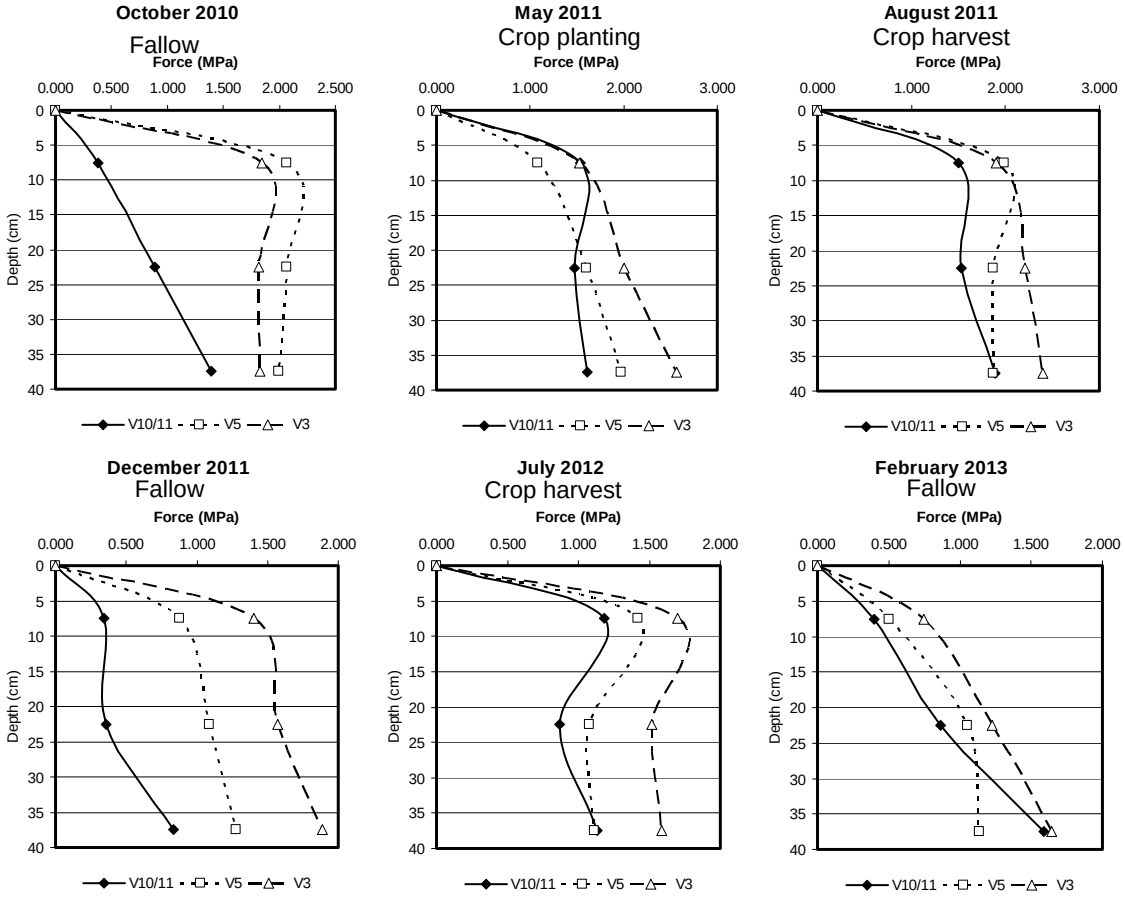

Figure 8-2: Penetration resistance at 0-15, 15-30 and 30-45 cm intervals down the soil profile in three zucchini fields V3, V5 and V10/11 at six separate times in the fallow and cropping phase.

Table 8-2: Mean soil chemical and physical properties across three fields, V3, V5 and V10/11 at the zucchini trial site.

		Oct 2010		May2011		Aug 2011		Dec 2011		July 2012		Feb 2013	
Sampling dates		**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**				**± SE**
Organic Carbon	%	1.8	± 0.1	1.6	± 0.1	1.8	± 0.1	1.9	± 0.2	1.7	± 0.1	1.5	± 0.1
pH	(1:5 w)	6.47	± 0.15	6.50	± 0.31	6.47	± 0.15	6.37	± 0.19	6.50	± 0.21	6.83	± 0.12
Elect. Conductivity	dS/m	0.237	± 0.024	0.323	± 0.107	0.237	± 0.024	0.323	± 0.035	0.127	± 0.022	0.137	± 0.009
Chloride	mg/kg	43	± 12	27	± 5	43	± 12	79	± 26	14	± 4	27	± 3
Nitrate Nitrogen (NO_3)	mg/kg	29.7	± 8.5	51.0	± 22.0	29.7	± 8.5	46.7	± 9.4	6.9	± 1.2	13.0	± 1.7
Phosphorus (Colwell)	mg/kg	160	± 6	180	± 21	160	± 6	150	± 6	133	± 7	120	± 10
Phosphorus Buffer Index (PBI-Col)		93	± 1	102	± 4	93	± 1	98	± 1	107	± 8	74	± 6
Available Potassium	mg/kg	260	± 26	250	± 17	260	± 26	303	± 19	213	± 9	197	± 27
Cation Exch. Cap.	Meq/100g	18.5	± 0.9	18.2	± 1.4	18.5	± 0.9	19.5	± 1.3	19.4	± 1.8	18.9	± 1.5
Calcium	Meq/100g	13.7	± 0.9	13.7	± 1.3	13.7	± 0.9	14.3	± 1.2	14.3	± 1.7	14.0	± 1.5
Potassium	Meq/100g	0.66	± 0.06	0.64	± 0.05	0.66	± 0.06	0.78	± 0.05	0.54	± 0.02	0.51	± 0.07
Magnesium	Meq/100g	4.0	± 0.0	3.7	± 0.1	4.0	± 0.0	4.0	± 0.1	4.2	± 0.2	4.0	± 0.1
Sodium	Meq/100g	0.24	± 0.03	0.20	± 0.04	0.24	± 0.03	0.38	± 0.02	0.24	± 0.04	0.31	± 0.07
Copper	mg/kg	2.7	± 0.2	3.2	± 0.2	2.7	± 0.2	3.5	± 0.3	3.2	± 0.3	2.4	± 0.2
Iron	mg/kg	126	± 24	157	± 17	126	± 24	160	± 35	160	± 30	103	± 19
Manganese	mg/kg	22	± 2	24	± 4	22	± 2	27	± 3	25	± 4	26	± 1
Zinc	mg/kg	6.0	± 0.3	6.3	± 0.4	6.0	± 0.3	6.7	± 0.3	5.4	± 0.2	4.8	± 0.2
Sulfate Sulfur	mg/kg	68.3	± 25.9	114.7	± 51.1	68.3	± 25.9	118.3	± 24.6	44.0	± 10.3	28.7	± 4.4
Bulk density	(g cm^{-3})	1.30	± 0.02	1.24	± 0.01	1.15	± 0.02	1.10	± 0.02	1.25	± 0.01	1.37	± 0.01
Porosity	(%)	43	± 1	45	± 0	49	± 1	51	± 1	45	± 1	39	± 0
Water Filled Pore Space	(%)	47	± 3	51	± 1	43	± 2	56	± 2	59	± 2	97	± 1

Table 8-3: Mean soil nematode community and biochemical properties of soils across three fields, V3, V5 and V10/11 at the zucchini trial site.

		Oct 2010		May 2011		Aug 2011		Dec 2011		July 2012		Feb 2013	
		Mean	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**	**Mean**	**± SE**
Total nematodes	100 g soil	1408	± 109	598	± 46	1728	± 190	1098	± 129	1105	± 104	807	± 123
Parasites	100 g soil	604	± 84	220	± 21	660	± 129	340	± 58	544	± 59	209	± 33
Parasites	%	42	± 5	37	± 3	37	± 4	30	± 2	49	± 2	29	± 4
Criconematids	100 g soil	0	± 0	0	± 0	4	± 2	2	± 2	22	± 16	4	± 2
H. dihystera	100 g soil	0	± 0	2	± 1	1	± 1	3	± 2	2	± 2	7	± 3
Meloidogyne sp.	100 g soil	0	± 0	3	± 2	7	± 4	0	± 0	0	± 0	0	± 0
Pratylenchus sp.	100 g soil	140	± 30	104	± 15	64	± 20	105	± 16	257	± 31	81	± 14
R. reniformis	100 g soil	251	± 38	50	± 14	297	± 80	70	± 14	92	± 28	55	± 16
Tylenchorhynchus sp.	100 g soil	213	± 39	62	± 12	286	± 81	160	± 37	171	± 28	62	± 18
Fungivores	100 g soil	320	± 42	129	± 13	465	± 66	291	± 36	294	± 34	155	± 18
Fungivores	%	22	± 1	23	± 3	28	± 3	30	± 2	28	± 3	33	± 6
Bacterivores	100 g soil	330	± 71	146	± 24	397	± 61	328	± 43	193	± 29	337	± 118
Bacterivores	%	25	± 6	23	± 2	23	± 3	27	± 2	16	± 2	22	± 3
Ba1	100 g soil	14	± 4	6	± 2	5	± 1	95	± 19	30	± 8	245	± 107
Ba2	100 g soil	6	± 1	11	± 2	16	± 2	233	± 34	155	± 25	90	± 13
Predator & Omnivores	100 g soil	156	± 34	103	± 14	207	± 42	138	± 20	74	± 17	106	± 16
Predator & Omnivores	%	11	± 2	17	± 2	12	± 2	13	± 2	7	± 1	15	± 2
Ca4	100 g soil	0	± 0	0	± 0	0	± 0	0	± 0	0	0	4	± 3
Om4	100 g soil	9	± 2	12	± 2	11	± 2	136	± 19	74	± 17	99	± 13
Taxa		9.3	± 0.3	9.5	± 0.2	10.1	± 0.4	9.6	± 0.3	8.8	± 0.3	9.8	± 0.5
B/(B+F) ratio		0.46	± 0.06	0.50	± 0.04	0.45	± 0.03	0.53	± 0.03	0.38	± 0.05	0.55	± 0.06
Diversity H'		1.93	± 0.03	1.98	± 0.03	1.94	± 0.06	2.02	± 0.02	1.88	± 0.03	1.92	± 0.08
Enrichment		64	± 3	56	± 4	53	± 2	55	± 3	48	± 2	68	± 5
Structure		48	± 7	61	± 4	49	± 4	49	± 4	38	± 5	62	± 3
Channel		49	± 7	53	± 6	57	± 3	49	± 6	74	± 5	37	± 8
Detrital		50	± 8	38	± 3	48	± 4	51	± 3	37	± 2	51	± 6
Predation		26	± 5	35	± 3	32	± 4	31	± 4	18	± 3	31	± 5
Roots		24	± 4	27	± 3	20	± 4	18	± 2	45	± 4	18	± 3
Labile C	mg g^{-1}	0.49	± 0.02	0.31	± 0.01	0.37	± 0.01	0.51	± 0.01	0.42	± 0.01	0.59	± 0.03
Fluorescein diacetate (FDA)	mg kg^{-1} hr^{-1}	5.0	± 1.4	7.7	± 0.7	14.5	± 1.3	12.3	± 0.6	9.1	± 0.5	22.1	± 1.9
β-glucosidase	µgPNG g^{-1} hr^{-1}	20.4	± 0.7	39.4	± 2.2	66.8	± 3.0	5.7	± 0.4	69.9	± 4.2	53.5	± 2.6

Table 8-4: Correlation matrix of physical, chemical, biochemical and nematode soil parameters at the zucchini trial site.**

30_45	0.63*	-																											
BF	-0.62*	-0.25	-0.07	-0.05	-																								
Ba1	-0.60*	-0.49	-0.11	0.38	0.46	-0.04	-																						
Cl	-0.46	-0.46	-0.17	-0.65*	0.42	-0.58*	0.14	0.34	0.18	-0.14	-																		
EC	-0.04	0.22	-0.15	-0.53	0.39	-0.58*	-0.22	0.01	0.01	-0.21	0.52	0.51	-																
EI	-0.55	-0.08	-0.39	0.33	0.63*	-0.23	0.51	-0.18	-0.28	0.17	0.25	0.24	0.11	-															
FDA	-0.58*	-0.26	-0.11	0.08	0.30	0.32	0.54	0.15	0.12	0.55	0.11	0.14	-0.31	0.33	-														
Fe	0.48	0.40	0.73*	-0.13	-0.12	-0.14	-0.23	0.18	-0.71	-0.36	-0.25	0.10	0.07	-0.28	-0.46	-													
Fu2	-0.32	-0.62*	0.39	-0.17	0.03	-0.05	0.32	0.94*	0.15	-0.02	0.13	0.00	-0.19	-0.19	0.18	0.17	-												
Heli	-0.49	-0.46	-0.14	0.14	0.09	0.06	0.73*	0.14	0.16	-0.10	0.21	-0.39	-0.25	0.18	0.39	-0.28	0.10												
K	-0.02	0.15	0.02	-0.66	0.24	-0.53	-0.17	0.12	-0.37	-0.32	0.66*	0.53	0.53	0.22	-0.20	0.33	-0.01	-											
LabC	-0.72*	-0.59*	-0.08	0.21	0.20	-0.22	0.50	0.31	0.29	0.57*	0.30	0.15	-0.31	0.47	0.60*	-0.48	0.34	-0.08	-										
Mn	-0.12	0.16	0.65*	-0.04	0.10	-0.16	0.19	0.26	-0.67	0.08	-0.03	0.31	-0.03	0.16	0.11	0.67*	0.25	0.29	0.11	-0.29	-								
Month	-0.46	-0.42	0.16	0.31	0.09	0.44	0.66*	0.48	0.10	0.37	-0.23	-0.16	-0.51	0.06	0.68*	-0.11	0.60*	-0.47	0.46	0.41	0.31	-							
NO3	-0.13	0.32	0.04	-0.55	0.45	-0.53	-0.22	-0.11	-0.27	-0.13	0.49	0.64*	0.84*	0.21	-0.21	0.24	-0.28	0.68*	-0.25	-0.61*	0.26	-0.47	-						
Na	-0.45	-0.63*	0.09	-0.19	0.41	-0.44	0.57*	0.65*	0.31	-0.16	0.50	-0.12	0.27	0.04	0.19	-0.22	0.49	-0.03	0.34	0.30	-0.07	0.30	0.06	-					
OC	-0.15	-0.27	-0.25	-0.62*	-0.12	-0.21	-0.33	0.04	0.29	-0.10	0.67*	0.21	0.11	-0.03	-0.06	-0.26	-0.03	0.56	0.16	0.29	-0.18	-0.40	0.17	-0.11	-				
Om4	-0.44	-0.60*	0.21	-0.06	0.16	-0.24	0.55	0.85*	0.25	0.08	0.17	-0.01	-0.07	-0.02	0.30	0.00	0.83*	-0.08	0.45	0.33	0.16	0.61*	-0.18	0.73*	-0.20				
P	0.48	0.64*	-0.01	-0.27	0.15	-0.33	-0.41	-0.34	-0.43	-0.48	0.03	0.23	0.72*	0.00	-0.64*	0.46	-0.46	0.45	-0.75*	-0.65*	0.02	-0.70*	0.69*	-0.16	-0.12	-			
PBI	0.37	0.00	0.44	-0.43	-0.11	-0.09	-0.51	0.26	-0.05	-0.47	0.03	-0.03	0.29	-0.60*	-0.69*	0.51	0.20	0.13	-0.63*	-0.07	0.02	-0.33	0.26	0.04	0.09	0.44			
Rot	0.67*	0.40	-0.04	0.05	-0.15	0.08	-0.32	-0.34	-0.19	-0.23	-0.12	-0.24	0.04	-0.13	-0.35	0.09	-0.39	0.01	-0.33	-0.07	-0.30	-0.46	-0.14	-0.11	-0.09	0.36			
S	0.10	0.20	-0.12	-0.39	0.22	-0.50	-0.20	0.16	0.10	-0.23	0.30	0.35	0.91*	-0.06	-0.37	0.12	-0.01	0.31	-0.37	-0.42	-0.08	-0.38	0.59*	0.32	-0.10	0.66*	-		
SI	0.17	0.37	-0.22	0.32	-0.06	-0.12	0.15	-0.22	-0.04	0.25	-0.28	0.19	0.25	0.09	-0.06	0.08	-0.29	-0.14	-0.12	-0.35	0.04	0.05	0.18	0.06	-0.57*	0.33	0.33		
Tax	-0.34	0.24	-0.15	-0.31	0.28	0.00	-0.18	-0.24	-0.06	0.58*	0.34	0.67*	0.24	0.35	0.43	-0.22	-0.28	0.37	0.28	-0.29	0.22	-0.04	0.49	-0.23	0.34	-0.01	-0.04		
Zn	0.29	0.19	0.06	-0.59*	0.11	-0.58*	-0.34	0.07	-0.02	-0.48	0.45	0.23	0.78*	-0.21	-0.56	0.36	-0.11	0.60*	-0.42	-0.28	-0.03	-0.60*	0.64*	0.23	0.20	0.69*	0.75*		
pH	-0.51	-0.55	-0.54	0.26	0.07	0.25	0.30	-0.03	0.77*	0.37	0.05	-0.25	-0.31	0.05	0.48	-0.85*	0.02	-0.53	0.43	0.46	-0.64*	0.32	-0.41	0.21	0.12	-0.62*	-0.32		
	0_15	30_45	Al	BD	BF	B_gluc	Ba1	Ba2	Ca	Ca4	Cl	Div	EC	EI	FDA	Fe	Fu2	K	LabC	Mg	Mn	Month	NO3	Na	OC	P	S		

* denotes significant correlation ($P<0.05$). 0_15 = penetration resistance 0-15 cm; 15_30 = penetration resistance 15-30 cm ; BD = bulk density; BF = bacterivores/(bacteriavores + fungivores); B_gluc = β-glucosidase; Ba1 = Bacterivores 1; Ba2 = Bacterivores 2; Ca4 = Predator 4; CEC = Cation exchange capacity; CI = Channel Index; Ca = Calcium; Div = Nematode diversity; EC = Electrical conductivity; EI = Enrichment index; FDA = Fluorescein diacetate; Fe = Iron; Fung = Fungivores; K = Potassium; L_C = Labile C; Mg = Magnesium; Mn = Manganese; NO3 = Nitrate nitrogen; OC = Organic carbon; P = Phosphorus; PBI = Phosphorus buffering index; Para = Plant-parasitic nematodes; P Om = Predatory and omnivorous nematodes; SI = Structure index; SO4 = Sulphate; Zn = Zinc; pH = pH(1:5 water); Tax = Number of nematode taxa identified. **Parameters with no significant correlations were deleted from the matrix table

Fields

A stepwise discriminant analysis successfully separated the three fields based on three parameters organic C, Fe and Cu (Figure 8-3). The leave-one-out cross validation method could predict each field successfully 100% of the time with knowledge of values from these three parameters (data not shown).

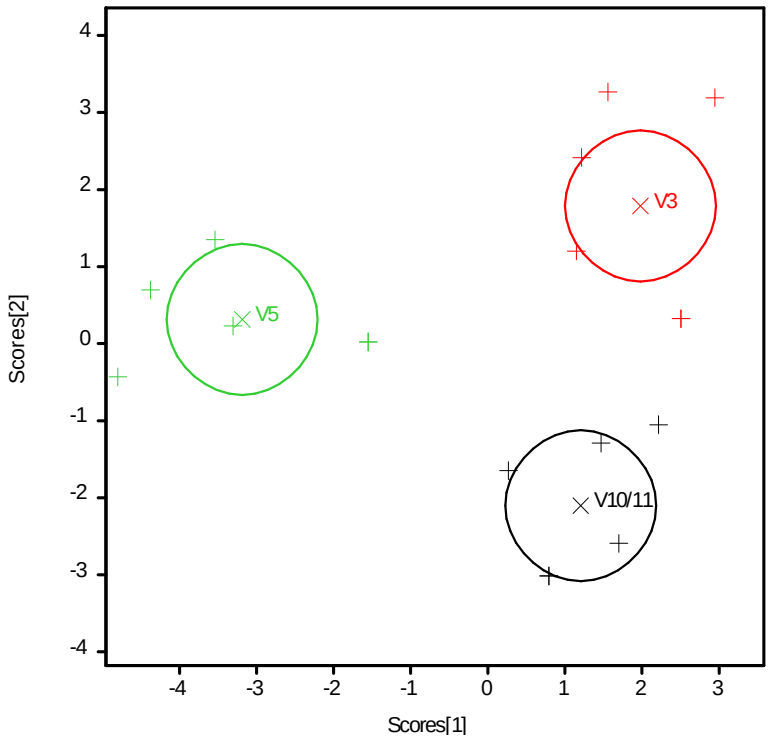

Figure 8-3: Discriminant analysis plot of three zucchini fields monitored for changes under minimum tillage and bed renovation using the soil parameters organic C, Fe and Cu

Box plots for each field were constructed for the three soil variables (Figure 8-4). The field V10/11, tended to have a greater median organic C content, 1.95%, relative to the other two fields V3 and V5 (Irrigation Valves 3 and 5, respectively), 1.55 and 1.6 respectively (Figure 8-4). There were two extreme outlying measurements in field V10/11 higher and lower than 50% of the organic C measurements (Figure 8-4). Field V3 had a greater Fe content with a median of 180 mg/kg, with very little overlap with the other two fields (Figure 8-4). Field V10/11 had the lowest Cu levels, with a median of 2.5 mg/kg relative to the other two fields V3 and V5 (Figure 8-4).

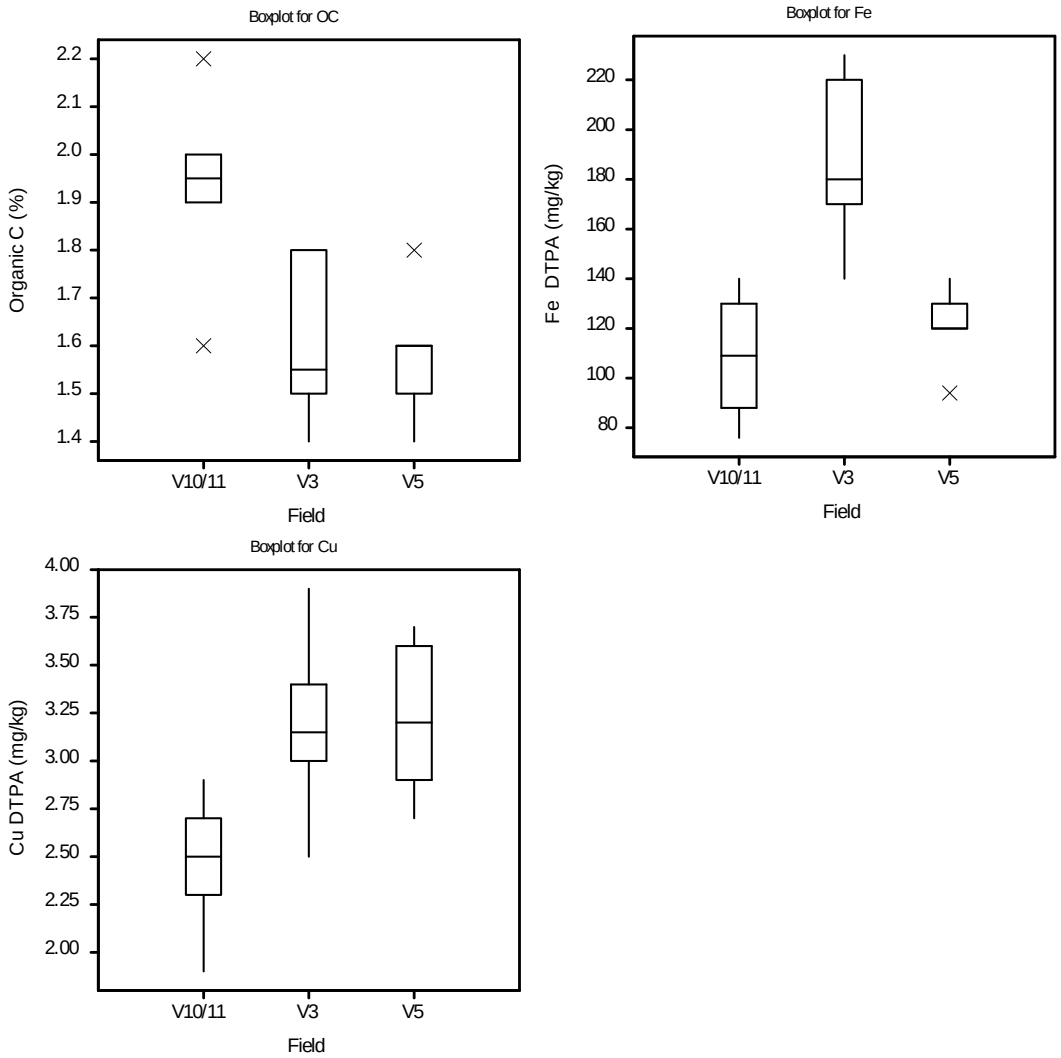

Figure 8-4: Box plots of soil properties, organic C, Fe and Cu used to discriminate between the zucchini fields. (n=6 for each field)

The same process of using a stepwise discriminant analysis was used to determine if the different cropping phase, either fallow or cropped, could be separated from each other. Two soil parameters labile C and β-glucosidase were successful in separating the two cropping phases (data not shown). The leave-one-out cross validation model suggested the phases were successfully separated 100% of the time with knowledge of labile C and β-glucosidase. The box plot for labile C demonstrated a higher median labile C value (0.52 mg/g) in the fallow phase, which was reduced in the cropping phase (0.36 mg/kg) (Figure 8-5). However, for β-glucosidase, the greatest median value was in the cropping phase (66.2 µgPNG g^{-1} hr^{-1}), which was reduced in the fallow phase (19.5 µgPNG g^{-1} hr^{-1}) (Figure 8-5). The fallow phase had a large spread with 50% of measurements ranging from 6.8 to 48 µgPNG g^{-1} hr^{-1} (Figure 8-5).

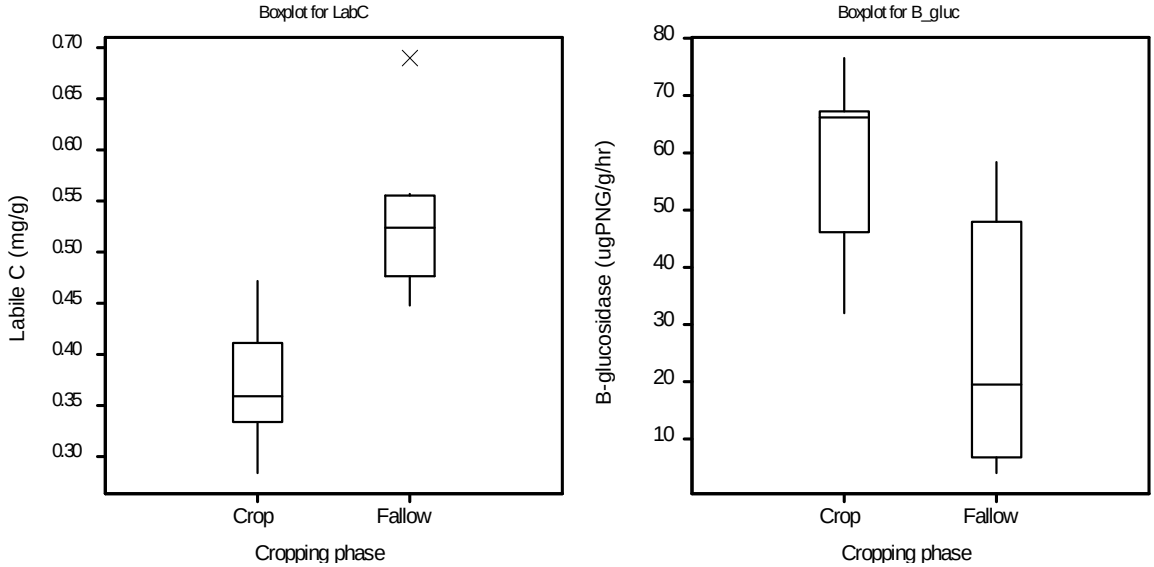

Figure 8-5: Box plots of soil properties, Labile C and β-glucosidase used to discriminate between the phases in cropping either cropped or fallow. (n = 36 for each crop phase).

Time interactions

Polynomial regression analysis of the soil properties over time could be divided into different reactions of the soil parameters measured in the three fields over the 29 months of monitoring. Soil parameters such as bacterivores belonging to the c-p group 1 (Ba1), fungivores (Fu2) and β-glucosidase followed seasonal patterns with no differences between fields (Figure 8-6). Soil parameters such as Ca, Fe, Mn, P, pH and organic C could be explained by a quadratic regression with the three different fields having parallel regression equations but different *y* axis intercepts (Figure 8-7). The soil parameters Cu, FDA and labile C could be explained by 3rd and 4th order polynomial regression with the fields having parallel regression equations but different *y* axis intercepts (Figure 8-8). The final group of soil parameters, *H. dihystera* and nematode community structure index, could be explained by 4th order polynomial equations with separate, non-parallel reaction between the fields (Figure 8-9).

The number of Ba1 nematodes tended to increase during the fallow phase and decline at planning of the zucchini crop (Figure 8-6). In contrast, the number of Fu2 nematodes remained low in the initial year of monitoring, increasing in the second year of fallow and remaining high in the second zucchini crop before declining in the third fallow (Figure 8-6). The model for β-glucosidase appeared to follow strongly the cropping phase with greater values during the cropping phase and reduced values in the fallow phase (Figure 8-6).

A quadratic regression model with parallel equations for the different fields could explain changes in six different soil variables (Figure 8-7). Organic C appeared to peak at the harvest of the first crop 10 months from commencement of monitoring; with the field V10/11 having significantly greater soil organic C throughout the 29 months of monitoring (Figure 8-7). The soil Ca peaked in the second zucchini crop 22 months after monitoring commenced, with the field V3 having significantly lower Ca levels than both V5 and V10/11 (Figure 8-7). The Fe levels in the soil appeared to peak during the second fallow crop, 14 months after monitoring commenced, with significantly greater Fe levels in V3 relative to V5 and V10/11 (Figure 8-7).

Similarly, the Mn levels were greater in V3 relative to V5 and V10/11, but the levels of Mn did not appear to peak until the third fallow crop around 29 months after monitoring commenced (Figure 8-7). The P levels in the soil declined at the same rate throughout the 29 month monitoring period, with significantly lower soil P in V10/11 relative to V5 and V3 (Figure 8-7). In contrast, to the other soil parameters measured, soil pH reached a minimum in the second fallow crop around 12 months after monitoring commenced and began to increase afterwards. The field V3 had significantly lower soil pH than V5 or V10/11 (Figure 8-7).

A cubic polynomial equation was used to describe changes in Cu and a quartic polynomial regression described the changes in labile C, and FDA (Figure 8-8). The amount of Cu in the soil appeared to peak in the second zucchini crop around 20 months after monitoring commenced, with field V10/11, having significantly lower levels than the other two fields, V3 and V5 (Figure 8-8). Labile C tended to follow a cyclical pattern with a decrease during the cropping phase, 6 and 20 months from commencement of the trial, which increased during the fallow phase, 15 and 29 months from the beginning of the trial (Figure 8-8). The field V10/11 had a significantly greater *y* axis intercept, but was parallel to field V5 and V3 (Figure 8-8). The FDA model followed a similar trend to labile C, with a significantly greater *y* axis intercept for field V10/11 relative to the V3 and V5 (Figure 8-8).

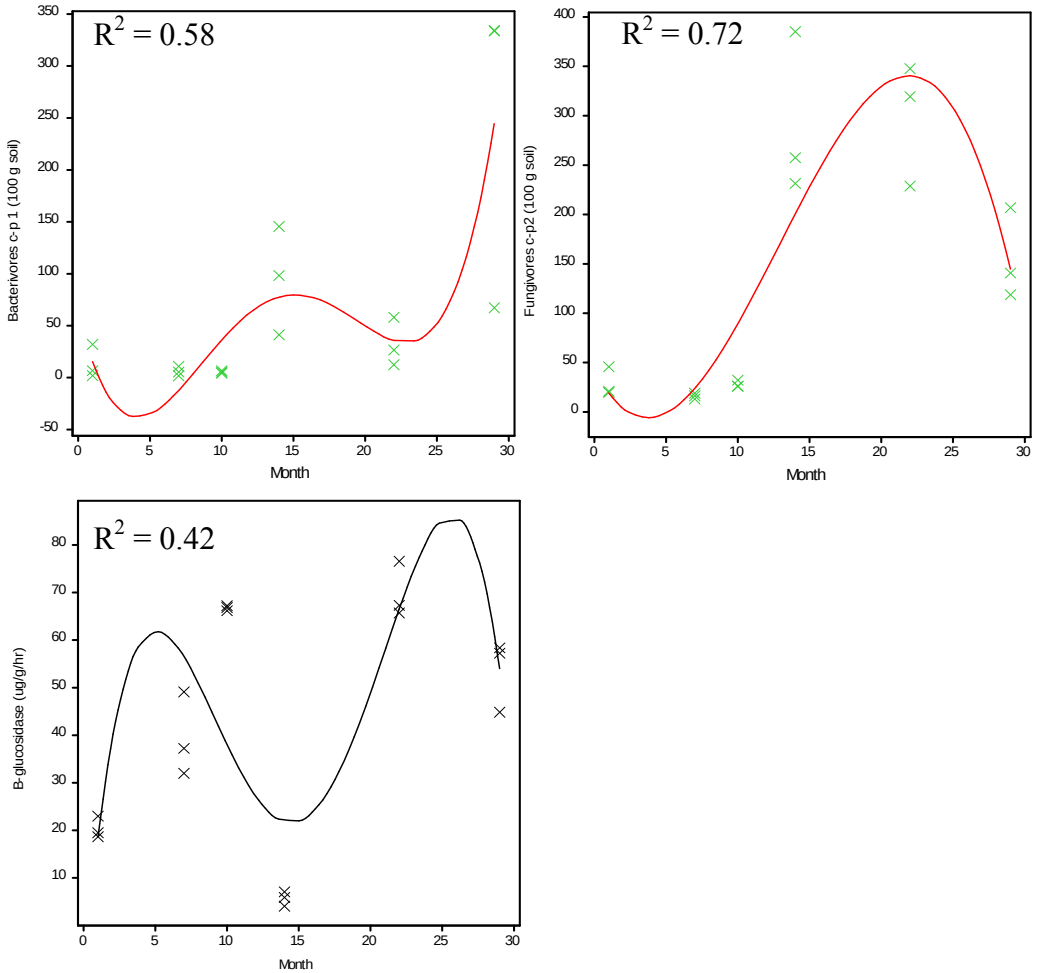

Figure 8-6: Polynomial regression of the soil parameters bacterivores c-p1, fungivores c-p2 and β-glucosidase over 29 months which included three fallow and two zucchinis crops using models with a common line.

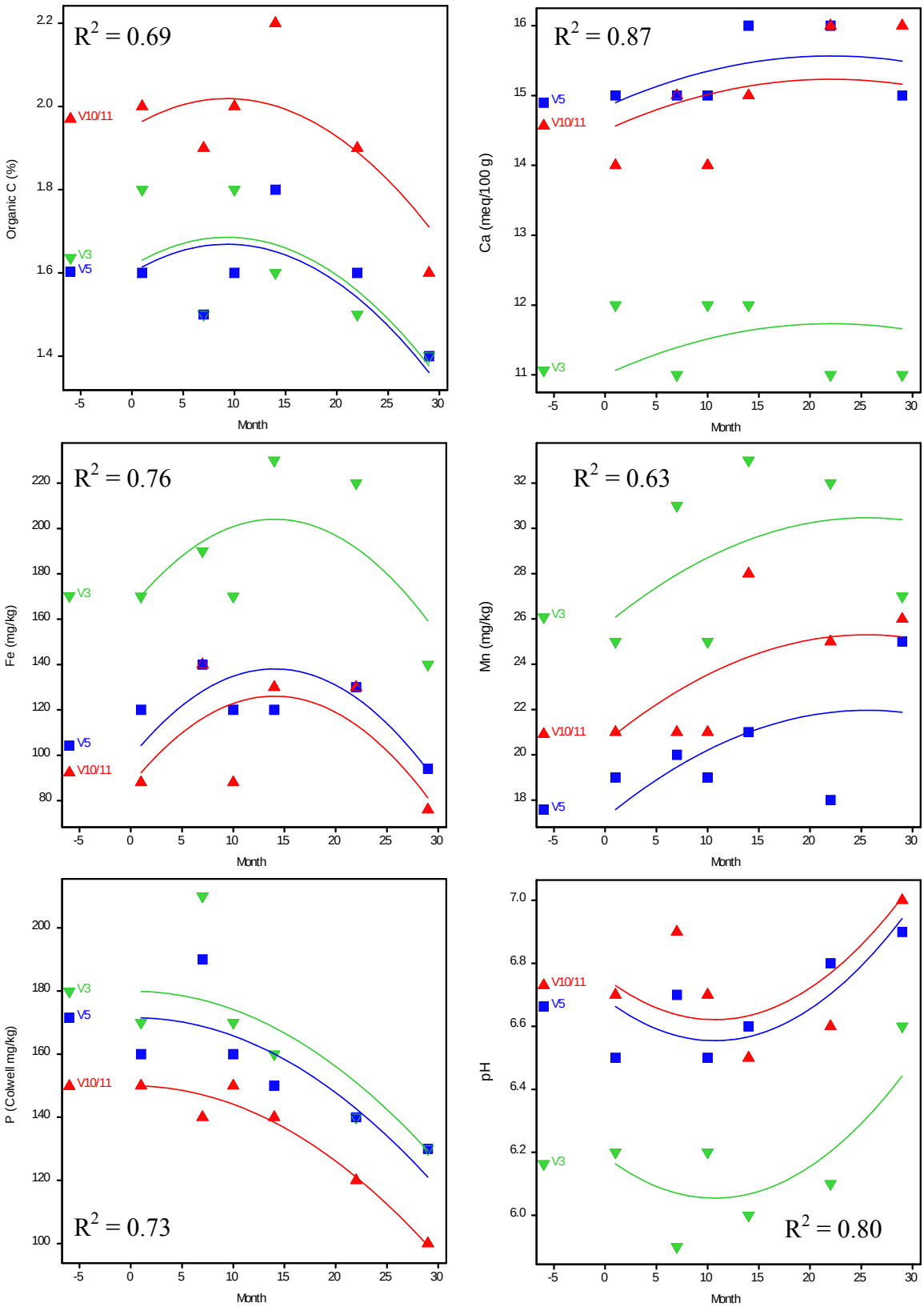

Figure 8-7: Quadratic regression of soil parameters organic C, Ca, Fe, Mn, P and pH from three fields over 29 months which included three fallow and two zucchinis crops using parallel models.

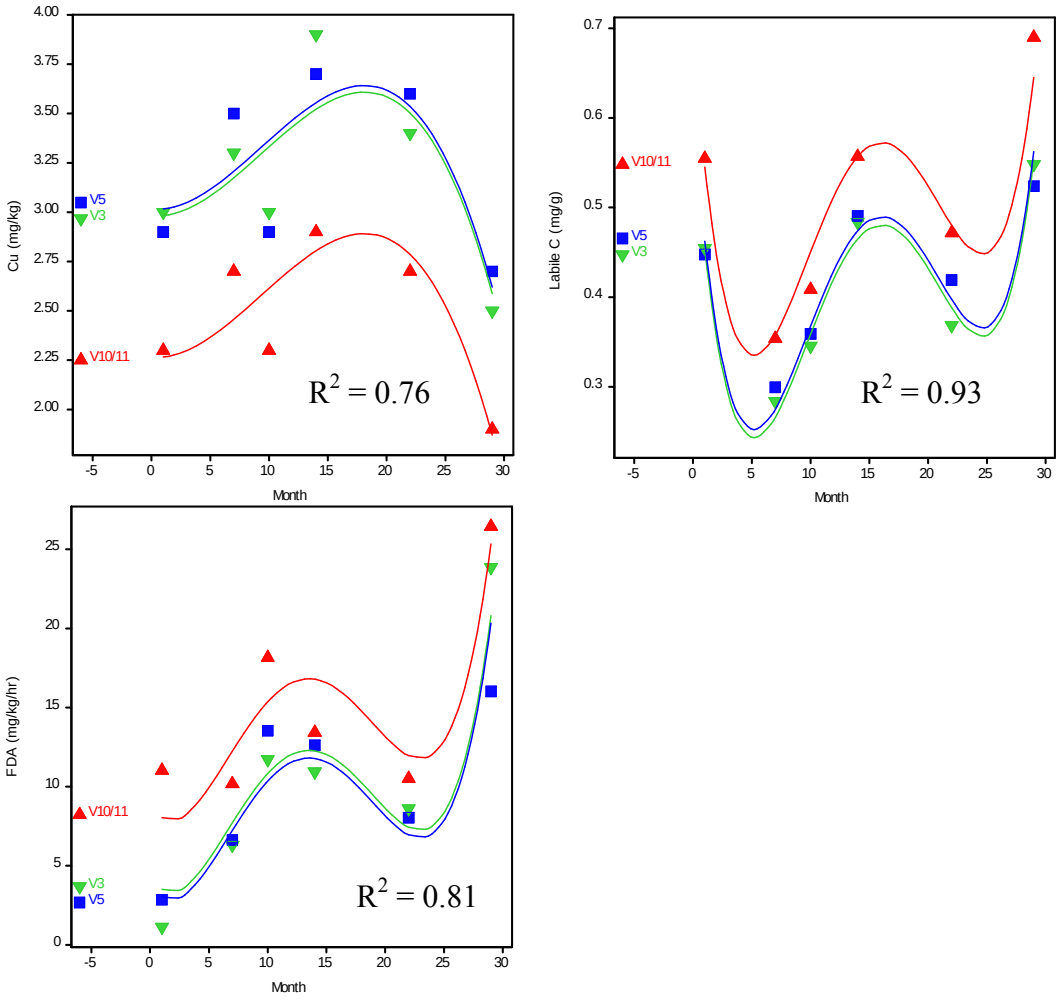

Figure 8-8: 3rd (Cu) and 4th (Labile C and FDA) order polynomial regression of labile C, organic C, FDA and β-glucosidase from three fields over 29 months which included three fallow and two zucchinis crops using parallel models.

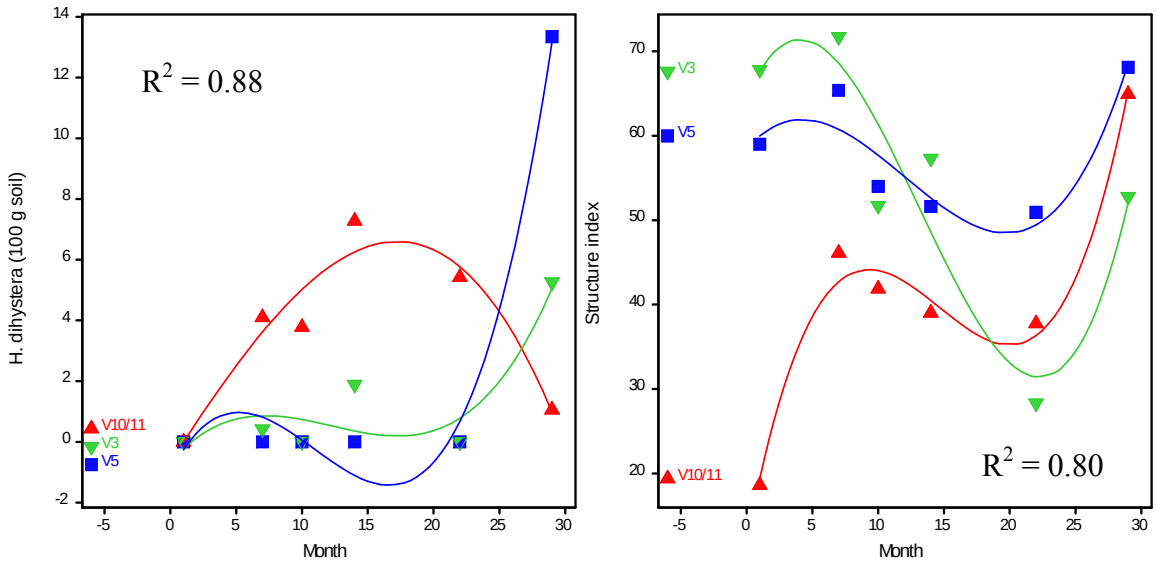

Figure 8-9: Polynomial regression of numbers of *H. dihystera* and structure index over 29 months which included three fallow and two zucchinis crops using independent models.

The number of *H. dihystera* and the nematode structure index acted independently over seasonal trends for the three different fields (Figure 8-9). The number of *H. dihystera* was low for the first 22 months of monitoring increasing in the final fallow crop 29 months after commencement (Figure 8-9). However, the number of *H. dihystera* in field V10/11 peaked in the second fallow crop, 16 months from commencement and then declined with increasing monitoring time (Figure 8-9). The structure index for fields V3 and V5 was relatively high compared to V10/11 at the commencement of monitoring and declined reaching a minimum in the second zucchini crop, 22 months after commencement, before increasing again in the third fallow crop, 29 months after monitoring commenced (Figure 8-9). However, field V10/11 started at a significantly lower level compared to the other two fields reaching a peak in the first zucchini crop, 10 months after commencement and then followed a similar trend to the fields V3 and V5 (Figure 8-9).

The linear correlation between soil variables is given in Table 8-4. However, this does not account for non-linear relationships. The variables were further investigated to determine non-linear relationships. Labile C was found to have a sigmoidal relationship with the penetration resistance of the soil 0-15 cm (Figure 8-10). When labile C reached a critical point approximately 0.45 mg/g there was a rapid decline in the penetration resistance until reaching a labile C of approximately 0.52 mg/kg (Figure 8-10). Similarly, there was a sigmoidal relationship between the penetration resistance in the top 15 cm of soil and the number of *R. reniformis* recovered from soil samples (Figure 8-10). Once the penetration resistance exceeded 1.52 MPa there was a rapid increase in the number of *R. reniformis* (Figure 8-10).

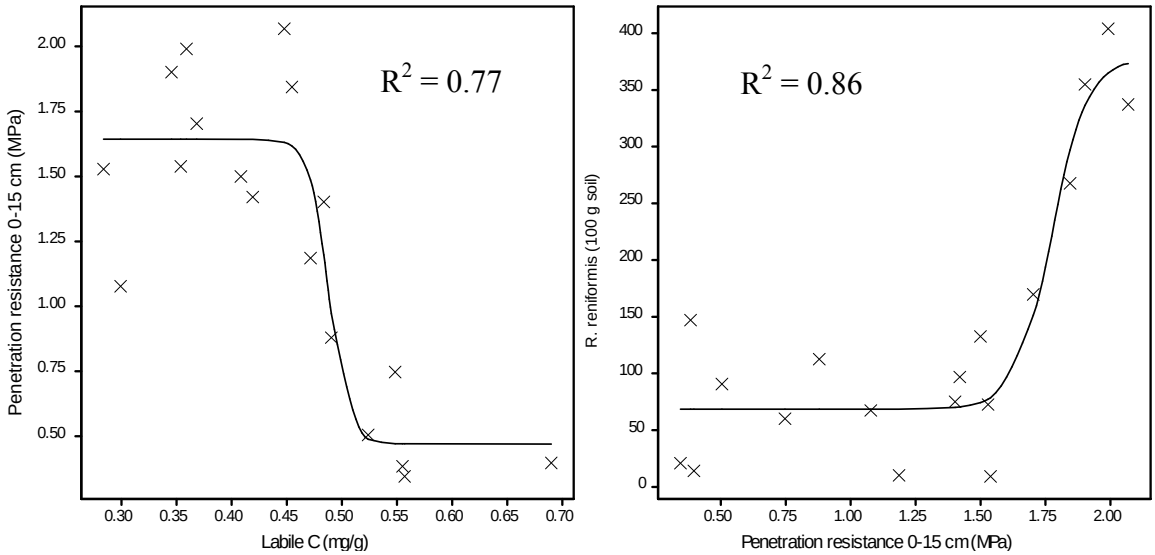

Figure 8-10: Sigmoidal relationship between soil properties, labile C and penetration resistance and penetration resistance and numbers of *R. reniformis*.

8.5. Discussion

The aim of this study was to determine if periodic renovation had a negative effect on ecological soil parameters in a vegetable production system. The renovation of the beds appeared to have only a temporary effect on soil biology, improving the overall soil health parameters under a minimum tillage system. The field V10/11 was a newly renovated field, which had a reduced nematode community structure index at the beginning of the trial. However, by the time the field was cropped to zucchinis, the nematode community had recovered and followed similar seasonal trends to the other fields throughout the monitoring period. The field V10/11 had a high organic and labile C level in the soil relative to the other fields. This may have given the field greater resilience and the ability to recover from the disturbance. Similar results were found by Sanchez-Moreno *et al.* (2006) who found that predatory nematodes were sensitive to physical disturbance. Therefore, using strategic tillage to renovate soil compaction, although reducing the nematode community structure, allowed other benefits. The greater organic C content, potentially allowed more rapid recovery of the cropping system, providing nutrient resources to allow the soil biology to stabilise.

It has also been suggested that no-tillage systems lead to a stratification of organic matter in the top soil (Minoshima *et al.* 2007; Morris *et al.* 2010). Therefore, the periodic renovation of the planting beds may allow organic matter to be mixed with the soil leading to greater redistribution of C in the soil profile. Field V10/11 had a greater organic C level following renovation, and the least organic C in this field was measured in May 2011 at the planting of the first zucchini crop. This suggested that some organic C may have been mineralised, which was supported by a reduction in labile C, but throughout the 29 month monitoring period there remained greater C sequestered in V10/11, with greater biological activity. The fields V3 and V5 had not been renovated for at least two years prior to the commencement of the trial and they demonstrated similar biochemical characteristics to one another, such as FDA, labile C, and pH.

Soil organic C in the minimum tillage system tended to follow a seasonal trend depending on the cropping phase, either fallow or cropped, with the labile C component driving many of the biological processes in the soil, particularly enzymatic soil functions. This has also been found in other cropping systems that reduce tillage and increase organic matter inputs such as sugarcane systems (Stirling *et al.* 2011). There appeared to be a build up of organic C in the fallow phase, which was planted with forage sorghum and cut at regular intervals. Interestingly the labile C changes acted independently of the soil organic C measured at each sampling period. The labile C appeared to be consumed in the cropping phase, reducing the amount of labile C in the soil. The seasonal trend of organic C pools and microbial activity allows a greater understanding of how to build soil C and may explain why it is sometimes difficult to measure consistent changes in new cropping systems such as sugarcane (Stirling *et al.* 2011). There appeared to be a general increase in microbial activity, determined by FDA measurements, with increasing labile C. Furthermore, labile C was a function of the soil P and the penetration resistance in the top 15 cm of the soil with these two parameters being able to explain 68% of the variation. However, β-glucosidase, the rate limiting enzyme in the degradation of cellulose, tended to increase in the cropping phase and decrease in the fallow phase. This suggested that organic matter was being consumed in the cropping phase by microbial

activity. Therefore, the accumulation of organic matter in the fallow phase when forage sorghum is grown, is an important component for soil functions for the cropping phase through nutrient mineralisation, nutrient cycling, and is the main stimulus for soil enzyme activity (Fageria 2012).

Strategic bed renovation may be useful in alleviating soil constraints to sustain crop productivity. Compaction in the top 15 cm of soil was one of the constraints identified on this farm with a sandy clay loam texture. Increased soil compaction is considered to be a limiting constraint to agricultural production under minimum tillage systems (Page *et al.* 2013; Unger and Blanco-Canqui 2012). The fields V3 and V5 had not been renovated for at least two years prior to the commencement of the trial and exhibited similar physical and biochemical characteristics to one another, such as soil profile penetration resistance, FDA, labile C, and pH. The alleviation of soil compaction as a constraint on this farm was linked to the increase in the amount of labile C in the soil. There appeared to be a critical labile C value of 0.50 mg/g for this soil type, where soil compaction would no longer be an issue in the top 15 cm.

The management of compaction also appeared to be critical for the management of plant-parasitic nematodes such as *R. reniformis*. Again there was a critical soil penetration value in the top 15 cm, 1.52 MPa, above which *R. reniformis* would increase in numbers. The increase in *R. reniformis* and penetration resistance may have been a function of the cropping season as toward the end of the cropping phase nematode numbers increased on zucchini roots and penetration resistance increased as irrigation became less frequent.

As agricultural producers increasingly reduce their inorganic nutrient inputs and increase their organic matter inputs, there is a greater reliance on biological processes to ensure that nutrients are mineralised in sufficient quantity to meet crop demands and to build soil structure. The understanding and validation of these processes are required to guide growers to ensure that they are overcoming the soil constraints and develop more ecologically viable cropping systems. Soil nutrient trends did not necessarily follow seasonal patterns like soil biochemical parameters. The expected trend of fluctuations of the major nutrients depending on the phase in the cropping cycle did not always occur (Table 7-2). It was expected that higher nutrient levels would occur during the cropping phase than during the fallow. There tended to greater Fe and Ca during the middle of the monitoring period, in the second fallow cycle. The fields V3 and V5 also had a greater Cu content which followed a seasonal trend peaking in the second zucchini crop. This may have reflected agrochemical applications, which suggested more copper based agrochemicals were needed to manage diseases in the fields that were older, since renovation. However, V3 demonstrated additional chemical differences having a greater Fe, Mn and lower Ca relative to the other fields. It has been suggested that organic matter fractions can form chelates that bind micronutrients such as Cu, Fe, Zn and Mn improving their availability to plants (Fageria 2012).

High levels of P were detected at the commencement of monitoring, which declined over the length of the trial, suggesting that the nutrient application was being monitored and applied only to crop requirements. Phosphorus is one of the nutrients which can pollute water ways and requires careful management in vegetable systems (Chan *et al.* 2007). A Colwell-P of 150 mg/kg in the surface soil was regarded as

sufficient for vegetable production (Chan *et al.* 2007). The Colwell P at the commencement of the trial was greater 150 mg/kg in all fields, but this declined over the 29 months of monitoring in all fields (Figure 8-6). The reduction in mineral P may be offset with an increase in soil organic matter driving an increase in soil biological activity, which has the potential to solublise and mineralize P from inorganic and organic pools of total P (Fageria 2012). Therefore, the potential for P to impact on the environment off the farm has reduced under the no-till system.

The trial site receives seasonal monsoonal rains and periodic inundation, increasing the need for good agricultural practices that protect the soil. The system developed for zucchini production was based on management practices to improve and stabilise organic matter in the soil through conservation agriculture, crop rotation, adequate use of fertiliser and maintaining a neutral soil pH. Conservation agriculture is defined as any tillage sequence with the objective of minimising or reducing the loss of soil and water and using tillage operations that leave greater than 30% of crop residue on the soil surface (Scopel *et al.* 2013). The conservation tillage system is coupled with crop rotation as a planned sequence alternating between zucchini and forage sorghum and monitoring nutrient application to ensure adequate supply of nutrients, without excess applications. As a procedure for seasonal vegetable production in tropical environments, this system has many advantages in soil management, relying heavily on soil organic matter to drive biological processes to build resilience and soil functions. The periodic renovation of the planting beds, approximately every 5 years, creates a biological disturbance, but the high organic matter creates resilience and the biology can recover with no adverse effects. However, forage sorghum has been found to have an allelopathic effect on crops reducing their productivity (Summers *et al.* 2009). Therefore, some caution is need when adapting the system for different crops in different environments.

By examining the soil food web it is possible to develop an understanding of how soil carbon may be moving through the different channels of the soil food web: either the detritus channel, in which C flows from microbes to nematode grazers; root channel in which C moves from plants directly to plant-feeding nematodes and the predator channel in which C flows from soil nematodes to their nematode predators (Pattison *et al.* 2013; Sánchez-Moreno *et al.* 2011). The microbivore channel is considered the fastest energy channel and opportunistic nematode grazers have rapid life cycles compared with plant parasitic nematodes (Sánchez-Moreno *et al.* 2011). The Ba1 nematodes and the Fu2 nematodes showed seasonal fluctuations independent of one another. The Ba1 nematodes responded to changes in the labile C in the soil, increasing in the fallow periods and declining during the crop period, which suggested that the nematodes could respond to increasing resources in the soil food web. This suggested that when a field is organically enriched these nematodes exploit the abundant resources and increase rapidly due to their short life cycle and high fecundity. Labile C is made of smaller fractions, which are most rapidly decomposed and made up of the living component or biomass and non-humic substances such as carbohydrates, amino acids, peptides, amino sugars, lipids, celluloses, waxes, and lignin (Fageria 2012). As the labile fractions are decomposed by bacteria, the Ba1 nematodes can respond increasing the amount of C moving through the microbivore channel. Bacterivores can influence C and N mineralisation by feeding on bacteria and excreting ammonia (Sanchez-Moreno *et al.* 2006). The Fu2 nematodes showed a general increase as the monitoring progressed but declined in the final fallow period

at 29 months. The final fallow sampling occurred when there was a high water filled pore space (WFPS), which may have inhibited soil fungal activity and reduced fungivorous grazers. The movement of C through the fungal channel in the soil was more closely related to movement basal activity of nematodes with a significant positive correlation between fungal feeding nematodes and Ba2 nematodes. The amount of C moving through either the bacterial or fungal channels in the soil was a function of the organic C level, bulk density, β-glucosidase and the WFPS. The combination of these four parameters could explain 72% of the times, whether soil organic C would pass through the bacterial or fungal microbial channels by soil organisms.

Sánchez-Moreno *et al.*(2011) suggested that nitrate-N could be considered as a surrogate indicator for agricultural disturbance. In the monitoring of the three zucchini fields, nitrate-N was positively correlated with increasing nematode diversity. This suggested that mineral nitrogen was limiting in this system and increases in nitrate-N stimulated greater nematode diversity in the soil. However, in the monitoring of the minimum tillage zucchini production systems, P appeared to be a greater indicator of disturbance, negatively correlated to labile C. The changes in labile C tended to dominate the soil biology, so that factors contributing to changes in labile C, such as soil P, had a greater impact on soil biology in this system than nitrate-N.

The soil food web refers to the organisms in the soil that are interdependent for sources of C as energy (Minoshima *et al.* 2007). Carbon enters the soil food web in the form of organic matter from plant litter or from root exudates. The consumption and biological transformation of the plant derived C by food web organisms can exit the soil as carbon dioxide or be incorporated into more stable humic substances (Coleman *et al.* 2004; Fageria 2012). Greater retention of C has been hypothesised to occur when soil organisms at a higher trophic level are more abundant due to greater C conserved in biomass, with gradual transformations to humic substances and protection of organic C in smaller soil aggregates (Minoshima *et al.* 2007). Soil food web dynamics are complex and reflect the integration of many factors, including cropping sequence, soil management and edaphic conditions. In highly disturbed soil the soil food web is composed of primary decomposers and herbivores. The lack of disturbance and the increase in organic matter inputs are hypothesised to increase fungi and soil food web complexity increasing the abundance of higher trophic level organisms and sequestering organic C in the soil.

Many soil organisms are more abundant in no tillage systems relative to conventional systems, although some organisms react positively to tillage due to rapid incorporation of organic matter into the soil, increasing its degradation rate (Sanchez-Moreno *et al.* 2006). Sanchez-Moreno *et al.*(2006) also hypothesised that higher trophic groups of nematodes, such as omnivores and predators were susceptible to disturbance. Furthermore, conventional cropping systems that included a bare fallow did not provide sufficient C to sustain predators and omnivores. This suggested in less disturbed systems, such as minimum tillage systems that the soil food web structure could be enhanced by C inputs.

8.6. Conclusion

The periodic renovation of beds in minimum tillage, vegetable production systems, was found to have no long term adverse effects on soil ecological processes. In contradiction, periodic renovation appeared to enhance soil functions by increasing nutrient recycling, overcoming compaction in the top 15 cm of soil and suppressing soil borne pest and disease organisms such as plant-parasitic nematodes. The mineralisation of organic C into the labile C pool appeared to drive the soil biological processes through a cyclical process, where organic and labile C would increase during the fallow phase under forage sorghum and decline during the cropping phase under zucchini. In contrast, organic matter degradation determined by β-glucosidase activity would increase in the cropping phase and decline in the fallow. The increased labile C appeared to be a key contributor to a reduction in compaction in the top 15 cm of soil. Furthermore, the reduction of soil compaction was a contributor to a reduction in the numbers of the plant-parasitic nematode, *Rotylenchulus reniforms*. This suggested that direct and indirect links are important in soil ecology under conservation agricultural systems, which rely heavily on the biological process to support crop productivity. The soil food web structure initially declined following renovation of the beds, but recovered showing enhanced resilience of the minimum tillage, organic mulch vegetable production system. The monitoring of the zucchini - forage sorghum, vegetable production systems has allowed the identification of soil constraints and contributed to a better understanding of the relationships between physical, chemical and biological processes in the soil to allow further improvements to the system.

8.7. References

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9. Commercial trials – NSW

9.1. Commercial grower demonstration trial – Valla, NSW

Introduction

Aphanomyces root rot (ARR) of beans is caused by *Aphanomyces euteiches* Drechs f.sp. *phaseoli* Pfend & Hag and was first reported on the north coast of NSW in the 1980's (Allen et al. 1987). This disease is a production issue in Australian bean crops, resulting in browning of the roots and lower stems, yield reduction and in severe cases crop devastation and plant death. Infection occurs when zoospores produced by the fungus move through water films to infect roots, with oospores allowing the fungus to survive for several years in soil. Infected root systems are also more susceptible to infection from other root pathogens like *Pythium*, *Rhizoctonia* and *Fusarium* spp. HAL funded project VG08043 'Development of methods to monitor and control Aphanomyces root rot and black root rot of beans' was led by Andrew Watson (NSW DPI) with collaborators from South Australia and Tasmania and was funded to investigate diagnostic assays and management strategies for ARR and other bean diseases (Watson et al. 2012).

The NSW project team working on VG08043 established a grower demonstration trial on the north coast of NSW to examine the effect of winter rotation treatments on ARR in the subsequent summer bean crops. The project teams for VG08043 and VG09038 collaborated on this trial in 2011-2012 to enhance the outcomes for industry. The VG09038 project team assisted with trial assessment and tested biological soil indicators in soil samples collected from the treatment plots.

Materials and methods

Trial details

The trial was located on a farm near Valla on the north coast of NSW. The typical rotation system employed on this farm was pasture / cattle and beans. Production issues in the bean crops include ARR and soil compaction. A sloping block approximately 50 m by 50 m was defined by an electric fence to exclude cattle. Cultivation and herbicides were used to reduce pasture growth. A demonstration trial was established in winter 2011, with no treatment replication (Figure 9-1).

Rotation treatments were applied during winter 2011. These crops were incorporated in December 2011 and beans were planted in March 2012 in 5 strips across the block. Bean plants were assessed one month after planting in April 2012 and soil samples were collected for greenhouse trials and processing. Further information about the trial is outlined in the final report prepared by Watson et al. (2012) for VG08043. The focus of the following chapter is the biological soil testing done by the VG09038 team. Microbial biomass carbon and FDA hydrolysis were measured by the NSW team and nematode populations were assessed by the Qld team.

Microbial Biomass Carbon

Microbial biomass C was determined using the chloroform fumigation extraction method of Vance et al. (1987). A 20 g portion of field moist soil was weighed into a beaker, with 6 replicates prepared for each sample. Three of the soil portions were fumigated using purified chloroform in a vacuum desiccator placed in the dark at 25ºC overnight (18-24 h). The 3 other soil portions were placed inside desiccators but without chloroform fumigation. The soil portions were then extracted using 80 ml of 0.5 M K_2SO_4. Total dissolved carbon of the soil extracts was measured using a Carbon Analyzer (Shimadzu) to measure the organic carbon in the aqueous solution (Wu et al., 1990). Biomass carbon was then calculated from the difference in carbon between the fumigated and non-fumigated soils and using a conversion factor of 2.64 (Wu et al., 1990).

Hydrolysis of Fluoroscein Diacetate (FDA)

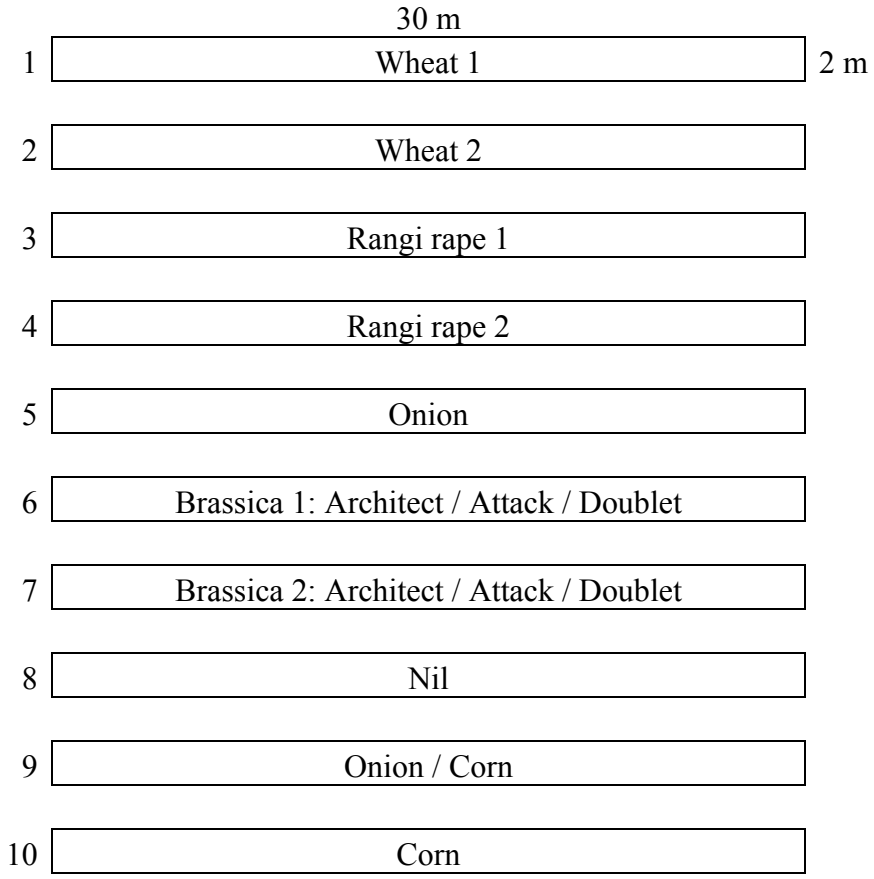
The method used for measurement of FDA hydrolysis was based on Green et al. (2006). A 1g soil sample (3 replicates tested per bulked soil sample) was added to 50 ml of 60 mM sodium phosphate buffer (pH 7.6) in a 50 ml tube. 0.50 ml of 4.9 mM FDA substrate solution was added before incubating at 37 °C for 3 h. The reaction was then stopped by adding 2 ml of acetone. A 30ml sub aliquot of the suspension was centrifuged at 8000 rpm for 5 mins (Sovral RC5). The supernatant was filtered (Whatman No.2) and 250 µl of filtrate from each sample was loaded onto a black 96-well plate (Nunc Black Microwell SI) along with the standards. Fluorescence was measured at 485 nm (excitation) and 535 nm (emission) using a Fluoroskan Ascent FL microplate reader (Thermo Electron Corporation, Vantaa, Finland). The amount of FDA hydrolysed was determined in reference to the standard curve.

Soil nematode populations

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g of field moist sub-sample was weighed onto a mesh sieve with a single ply of tissue and placed into a tray with 250 mL of water for 48 hours. The nematodes were collected on a 25 µm sieve and backwashed into a vial. The total number of nematodes was estimated and a 50 µL aliquot was placed on a glass slide. A minimum of 100 individual nematodes were identified to genus for plant-parasites and family for free-living nematodes.

Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores, predators). Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index and the ratio of bacterivores and fungivores was calculated (Yeates and Bongers 1999). Additionally, the weighted functional guilds analysis concept was applied, without plant parasites to determine the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris *et al.* 2001).

Figure 9-1: Valla bean demonstration trial – field plan – winter rotation 2011



Results and discussion

The disease ARR was present in the field trial soil and disease symptoms were observed on some plants (Figure 9-2) although levels of ARR in the 2012 bean crop were lower than previous years. This could be due to weather conditions (i.e. minimal wetting periods) or a general decline in *Aphanomyces* inoculum in the block. The Brassica and Rangi rape treatments experienced significantly less disease than the control, and the wheat rotation had little impact (Watson et al. 2012).

These results were not reflected in the measurements of biological activity recorded in soil samples collected at the time of crop assessment. There was little difference in FDA hydrolysis and no consistent patterns in the levels of microbial biomass carbon or nematode populations (Table 9-1 and Table 9-2). Although it does appear that the soil environment under the Brassica plants favoured bacteria, whereas wheat increased the number of fungivores (Table 9-2). The biological indicators measured in this trial were considered to be potentially useful indicators of soil health because they were influenced by the chemical and physical properties of the soil (Alabouvette *et al*. 1996), which in turn were affected by management practices. Soil organisms also respond to management in time scales that were relevant to land managers (Pankhurst 1994). In particular soil dwelling nematodes were found to be effective biological indicators of soil health due to their ability to respond to changes in the soil physical and chemical environment (Neher 2001; Pattison et al, 2008). It may be that some rotation treatments, like the Brassicas, induced specific changes in the soil that affected Aphanomyces, but did not affect general biological activity or populations of an unrelated organism (i.e nematodes). Therefore, the rotation treatments had a significant effect on ARR disease but not on the general biological indicators that were measured although the lack of trial replication means that these results are only a guide. In the absence of fully replicated trials, the level of disease expressed in the demonstration bean crop is a suitable biological indicator to direct practice change on this property.

Figure 9-2: Valla bean trial - symptoms of Aphanomyces root rot expressed in a bean plant, April 2012

Figure 9-3: Valla bean trial - Andrew Watson (NSW DPI, Yanco) undertaking disease assessments, April 2012

Table 9-1: Valla bean trial – biological indicators measured in soil samples collected at time of harvest of bean crop April 2012

Treatment*	Biomass C (µg/g OD soil)	FDA Hydrolysis (µg/g OD soil /min)
Wheat bed 1	359.89	1.77
Wheat bed 2	240.68	1.67
Rangi rape bed 1	171.22	1.60
Rangi rape bed 2	181.84	1.71
Brassica bed 1	321.55	1.65
Brassica bed 2	214.4	1.65
Onion	300.41	1.86
Onion / Corn	302.68	1.95
Corn	502.34	1.66
Nil	378.39	1.47
Outside block	436.99	1.79
Pasture over fence	612.64	2.04

* winter/spring rotation treatments prior to bean crop

Table 9-2: Valla bean trial – nematode populations recorded in soil samples collected at time of harvest of bean crop April 2012

Treatment plot	Nematodes / 100 g soil						Shannon-Weiner diversity index (H')	Dominance	Enrichment index EI	Structure index SI	Channel index CI	B:F ratio	Parasites: Free livers
	Total nematodes	Plant parasitic	Fungal feeding	Bacterial feeding	Predatory	Omnivores							
Wheat 1	3320	57	1431	1202	0	630	2.06	0.16	77	62	27	0.46	0.02
Wheat 2	4410	136	2307	1153	0	814	2.16	0.13	68	57	41	0.33	0.03
Ranji rape 1	3251	97	1698	631	0	825	2.11	0.14	65	64	49	0.27	0.03
Ranji rape 2	3169	107	1504	645	0	913	2.04	0.15	69	69	41	0.30	0.03
Brassica 1	1120	80	280	640	20	100	2.12	0.16	74	52	18	0.70	0.07
Brassica 2	1621	31	550	764	31	245	1.96	0.17	74	55	23	0.58	0.02
Onion with Planter	4801	215	1648	1648	0	1290	1.92	0.16	64	68	37	0.50	0.04
Onion/Corn	3420	204	1072	1378	0	766	2.01	0.15	66	64	30	0.56	0.06
Corn	2740	45	719	1482	45	449	1.99	0.17	74	61	19	0.67	0.02
NIL	3900	368	1545	1030	74	883	2.02	0.16	73	68	32	0.40	0.09
Outside block	3440	111	1387	1276	0	666	2.14	0.13	68	59	34	0.48	0.03
Pasture over fence	2419	255	594	1061	0	509	2.09	0.16	83	75	16	0.64	0.11

B:F = ratio of bacterivores to fungivores

9.2. Commercial grower demonstration trials – Richmond, NSW

Introduction

Three grower demonstration trials were established in the Sydney basin by Darren Fahey (Compost NSW Market and Industry Development Officer) in January 2010 to compare different rates of compost with conventional management in vegetable production systems.

Materials and methods

Trial details

Three trials were established that compared rates of 20m^3 (8.4 dry t), 40 m^3 (16.8 dry t) and 60 m^3 (25.2 dry t) of compost per hectare with conventional fertiliser management on the demonstration farms. Trial 1 was a capsicum crop, trial 2 a broccoli crop and a potato crop was grown in the third trial. Production data was collected and a number of soil properties were measured.

The NSW DPI project team provided biological testing of the soil samples collected from all 3 trials before and after compost application at 3 rates; 20, 40 and 60 dry t / ha. Microbial biomass carbon and FDA hydrolysis were measured in soil samples collected at planting and harvest.

Microbial Biomass Carbon

Microbial biomass C was determined using the chloroform fumigation extraction method of Vance et al. (1987). A 20 g portion of field moist soil was weighed into a beaker, with 6 replicates prepared for each sample. Three of the soil portions were fumigated using purified chloroform in a vacuum desiccator placed in the dark at 25ºC overnight (18-24 h). The 3 other soil portions were placed inside desiccators but without chloroform fumigation. The soil portions were then extracted using 80 ml of 0.5 M K_2SO_4. Total dissolved carbon of the soil extracts was measured using a Carbon Analyzer (Shimadzu) to measure the organic carbon in the aqueous solution (Wu et al., 1990). Biomass carbon was then calculated from the difference in carbon between the fumigated and non-fumigated soils and using a conversion factor of 2.64 (Wu et al., 1990).

Hydrolysis of Fluoroscein Diacetate (FDA)

The method used for measurement of FDA hydrolysis was based on Green et al. (2006). A 1g soil sample (3 replicates tested per bulked soil sample) was added to 50 ml of 60 mM sodium phosphate buffer (pH 7.6) in a 50 ml tube. 0.50 ml of 4.9 mM FDA substrate solution was added before incubating at 37 °C for 3 h. The reaction was then stopped by adding 2 ml of acetone. A 30ml sub aliquot of the suspension was centrifuged at 8000 rpm for 5 mins (Sovral RC5). The supernatant was filtered (Whatman No.2) and 250 µl of filtrate from each sample was loaded onto a black 96-well plate (Nunc Black Microwell SI) along with the standards. Fluorescence was measured at 485 nm (excitation) and 535 nm (emission) using a Fluoroskan Ascent FL microplate reader (Thermo Electron Corporation, Vantaa, Finland). The amount of FDA hydrolysed was determined in reference to the standard curve.

Results and discussion

The results reported by Darren Fahey showed that compost application can increase yields and water savings are achievable in the three vegetable crops trialled. Less club root disease was also observed in the broccoli harvested from the compost treatments. However there were no significant differences or consistent trends in the biological indicators that were measured (Table 9-3). These results are only a guide; fully replicated trials would be needed in order to make firm conclusions.

Further trials were planned at the 3rd trial site for a potato crop that was to be planted during winter 2010 involving compost, conventional fertiliser and control (i.e. no fertiliser or compost) plots. The grower then decided to leave the industry and the trial site was abandoned.

Table 9-3: Richmond compost trials – biological activity measured in soil samples collected before and after compost application, 2010

Sample tested	Before compost application		After compost application	
	Mean soil respiration rates (µg CO2-C/g OD soil/h)	Microbial biomass C (µg C/g OD soil)	Microbial biomass C (µg C/g OD soil)	Mean FDA fluorescence (µg FDA hydrolysed / g OD soil / min)
Trial site 1 - capsicum				
Control	0.28	259.01	178.62	1.21
20	0.29	190.27	258.50	1.06
40	0.23	291.60	246.92	1.12
60	0.22	206.45	266.52	0.96
Trial site 2 - broccoli				
Control	0.34	76.25	107.78	1.23
20	0.34	91.95	38.43	1.32
40			75.45	1.27
60			114.58	1.26
Trial site 3 - potato				
Control	0.18	169.68	105.11	0.99
20	0.26	91.92	80.32	1.16
40			68.98	1.13
60			96.72	0.87

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10. Greenhouse pot trials – NSW

10.1. Introduction

Greenhouse pot trials were conducted to investigate the ability of different organic amendments to induce disease suppression, using a model host / pathogen system. The model system is Aphanomyces root rot (ARR) on beans caused by *Aphanomyces euteiches* f.sp. *phaseoli*. The organic amendments that were investigated include locally sourced compost and two biochars derived from different source materials. Treatments also explored the effect of calcium in combination with plant derived biochar.

Crop and root health was assessed during each harvest of the NSW DPI long term vegetable field trial and no soil-borne disease issues were detected over the 12 crops grown to date. The long term field trial cannot be field inoculated with a pathogen so the potential of composted garden organics (cGO) to suppress disease was assessed by inoculating undisturbed soil cores from the long term trial with the model pathogen and planting a susceptible host (i.e. Aphanomyces and beans). The suppressive potential of a number of organic amendments was also tested in pot trials using traditional potting media.

A number of pilot trials were conducted to optimise the method using the model host / pathogen system in both the undisturbed soil cores and traditional potting media. The final optimised trials are presented in this chapter.

10.2. Methods

The work was undertaken in a controlled environment greenhouse in the research nursery at NSW DPI's Elizabeth Macarthur Agricultural Institute.

Bean seedlings (variety Redlands New Pioneer: source Sunland Seeds) were raised in seedling raising mix before transplanting to undisturbed soil cores or potting media.

Undisturbed soil cores: Twenty cm lengths of 90 mm diameter PVC pipe were used to obtain 15 cm deep undisturbed soil cores from the NSW DPI CROA long-term trial site. Three cores were collected from each of the 28 plots. The cores were transported back to the EMAI nursery and placed in a controlled environment greenhouse. It should be noted that the trial treatments had already been applied to the treatment plots in the field; composted garden organics (cGO) and inorganic fertiliser were not applied to the undisturbed cores.

Potting media trial: Sixteen pots were prepared per treatment, eight of which were inoculated. The soil treatments were applied as per the label rate and mixed into the top few cm of soil UC potting media in pots. Five different amendments were trialled:

1. Compost – from the local quarry (source: Collins Rich Earth Compost),

2. AGRICHAR^{TM} Soil Amendment – derived from green waste (source: Pacific Pyrolysis)
3. Biochar – derived from animal waste (source: www.blackearthproducts.com.au),
4. Plant derived biochar plus lime
5. Lime

A culture of *Aphanomyces euteiches* f.sp. *phaseoli* was obtained from Andrew Watson, NSW DPI Yanco. Several subcultures were made on ¼ PDA. A spore solution was prepared by macerating culture plates in sterile distilled water, 50 mL per plate creating 10^5 spores/mL solution.

Once beans reached first true leaf, three beans were prepared per pot. Individual bean plants were washed and the roots injured using a scalpel. The injured bean roots were then dipped into a spore solution for 1 minute and transplanted to a treatment pot (3 bean plants / pot). Three beans were planted per treatment pot or undisturbed soil core. 50mL of spore solution was then poured onto each pot. After 48hrs, pots were watered three times a day for the 3 days with equal amounts of water.

The main point of difference between the 2 potting media trials was that in pot trial 1 bean seedlings were immediately transplanted into the amended pots, whereas in pot trial 2 bean seedlings were not transplanted into the pots until 2 weeks after the soil treatments were added.

Three weeks after inoculation the bean plants were rated for disease. Hypocotyl symptoms and root infection were scored on a scale of 0-5; where 0 is no symptoms and 5 is severe symptoms resulting in death.

After symptom assessment, plants were placed in paper bags, oven dried and weighed.

Subsamples of treated potting media were also tested for biological activity.

Microbial Biomass Carbon

Microbial biomass C was determined using the chloroform fumigation extraction method of Vance et al. (1987). A 20 g portion of field moist soil was weighed into a beaker, with 6 replicates prepared for each sample. Three of the soil portions were fumigated using purified chloroform in a vacuum desiccator placed in the dark at 25ºC overnight (18-24 h). The 3 other soil portions were placed inside desiccators but without chloroform fumigation. The soil portions were then extracted using 80 ml of 0.5 M K_2SO_4. Total dissolved carbon of the soil extracts was measured using a Carbon Analyzer (Shimadzu) to measure the organic carbon in the aqueous solution (Wu et al., 1990). Biomass carbon was then calculated from the difference in carbon between the fumigated and non-fumigated soils and using a conversion factor of 2.64 (Wu et al., 1990).

Hydrolysis of Fluoroscein Diacetate (FDA)

The method used for measurement of FDA hydrolysis was based on Green et al. (2006). A 1g soil sample (3 replicates tested per bulked soil sample) was added to 50 ml of 60 mM sodium phosphate buffer (pH 7.6) in a 50 ml tube. 0.50 ml of 4.9 mM FDA substrate solution was added before incubating at 37 °C for 3 h. The reaction was then stopped by adding 2 ml of acetone. A 30ml sub aliquot of the suspension was centrifuged at 8000 rpm for 5 mins (Sovral RC5). The supernatant was filtered (Whatman No.2) and 250 µl of filtrate from each sample was loaded onto a black 96-well plate (Nunc Black Microwell SI) along with the standards. Fluorescence was measured at 485 nm (excitation) and 535 nm (emission) using a Fluoroskan Ascent FL microplate reader (Thermo Electron Corporation, Vantaa, Finland). The amount of FDA hydrolysed was determined in reference to the standard curve.

Statistical analysis

The mean average disease scores were analysed using an ANOVA.

10.3. Results and discussion

The addition of compost appeared to induce disease suppression in a model host / pathogen system in pot trials performed in traditional potting media, although this was not found in undisturbed soil cores taken from the long term compost field trial (Table 10-1). There was only one successful trial involving the undisturbed soil cores, therefore, replication is required before firm conclusions can be drawn. However, clear symptoms of Aphanomyces root rot were observed in pot trials using both undisturbed soil cores and traditional potting media (Figure 10-1).

Bean plants grown in UC mix treated with compost and inoculated with *A. euetiches* f.sp. *phaseoli* had significantly less severe symptoms of ARR and significantly greater plant growth, compared with the other treatments (Table 10-2; Figure 10-2). There also appeared to be much greater biological activity in compost amended pots, as indicated by significantly greater readings for microbial biomass carbon and FDA hydrolysis (Table 10-2; Figure 10-2). Pots treated with biochar derived from plants had less disease than those treated with animal derived biochar, and calcium appeared to enhance this effect.

The ability of compost to induce disease suppression is known and has been reported in several studies (Baker and Cook 1974; Hoitink and Fahy 1986) including for *Aphanomyces euteiches* (Lumsden et al. 1983). However inconsistent results means suppression is not guaranteed in every production system with every compost and soil type making it difficult for growers to make practical decisions (Bonanomi et al. 2010). There is also a paucity of data on the effect of biochar on the activity of the microbial buffer and disease suppression. Whilst biochar did not outperform compost in these pot trials using beans / ARR as the model system, there is a need to further explore the effect of biochar on soil-borne disease given the widespread interest in the product. There does appear to be some potential for plant derived biochar in particular

for vegetable production which could be explored further via pot trials, fully replicated field trials and under different model systems. Pot trials are currently in progress at EMAI using cucumbers and vascular wilt caused by *Fusarium oxypsorum* f.sp. *cucumerinum* as the model host / pathogen system. Further work is needed to improve the method using undisturbed soil cores to make the results of the pot trials more relevant to the field situation.

Table 10-1: The effect of organic amendments on a model host / pathogen system (beans / Aphanomyces root rot ARR) in pot trials using undisturbed soil cores sampled from the NSW DPI long term vegetable field trial

Treatment	Mean ARR score
conventional, hP	3.67 ab
cGO, hP	3.56 ab
mixed, hP	3.67 ab
conventional, lP	3.25 b
cGO, lP	4.11 a
mixed, lP	3.81 ab
control	3.89 a
sed	0.270
lsd 5%	0.567

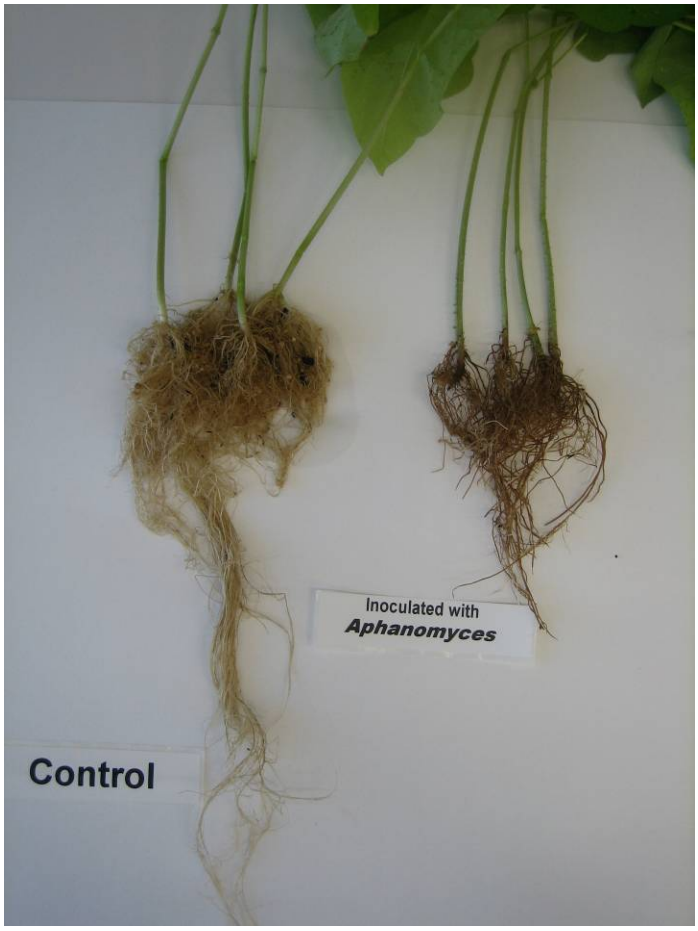

Figure 10-1: Bean roots inoculated with *Aphanomyces euteiches* f.sp. *phaseoli*, compared with 'healthy' uninoculated control roots

Table 10-2: The effect of organic amendments on a model host / pathogen system (beans / Aphanomyces root rot ARR) in pot trials using traditional potting media (UC mix)

Treatment	Trial 1				Trial 2			
	ARR score	**Bean plant dry weight (g)**	**Microbial biomass C** (µg C/g OD soil)	**Mean FDA fluorescence** (µg FDA hydrolysed / g OD soil / min)	**ARR score**	**Bean plant dry weight (g)**	**Microbial biomass C** (µg C/g OD soil)	**Mean FDA fluorescence** (µg FDA hydrolysed / g OD soil / min)
Compost	4.3	2.38	326.28	1.43	2.92	4.06	494.65	1.57
Biochar (plant)	4.7	2.16	90.04	0.80	3.96	1.55	201.96	1.13
Biochar (plant) + Ca	4	2.24	66.51	0.70	3.71	1.85	139.65	1.25
Biochar (animal)	5	1.91	87.93	0.64	4.33	1.21	130.58	1.48
Ca	4.5	1.48	78.42	0.91	3.79	1.76	205.44	1.22
Nil	4.6	1.61	85.31	0.90	4.42	1.61	144.33	1.38

Table 10-3: The effect of organic amendments on a model host / pathogen system (beans / Aphanomyces root rot ARR) in pot trials using traditional potting media (UC mix) – data from 2 pot trials combined for analysis

Treatment	ARR score	Bean plant dry weight (g) whole plant	Bean plant dry weight (g) top of plant	Microbial biomass C (µg C/g OD soil)	Mean FDA fluorescence (µg FDA hydrolysed / g OD soil / min)
Compost	3.67	2.63	2.35	488.9	1.92
Biochar (plant)	4.33	0.84	0.91	189.0	1.03
Biochar (plant) + Ca	3.85	1.38	1.26	104.9	1.02
Biochar (animal)	4.67	0.53	0.66	134.1	1.38
Ca	4.13	0.93	1.11	173.9	1.09
Nil	4.50	0.62	0.86	126.9	1.32
lsd 5%	0.67	0.57	0.42	88.9	0.22

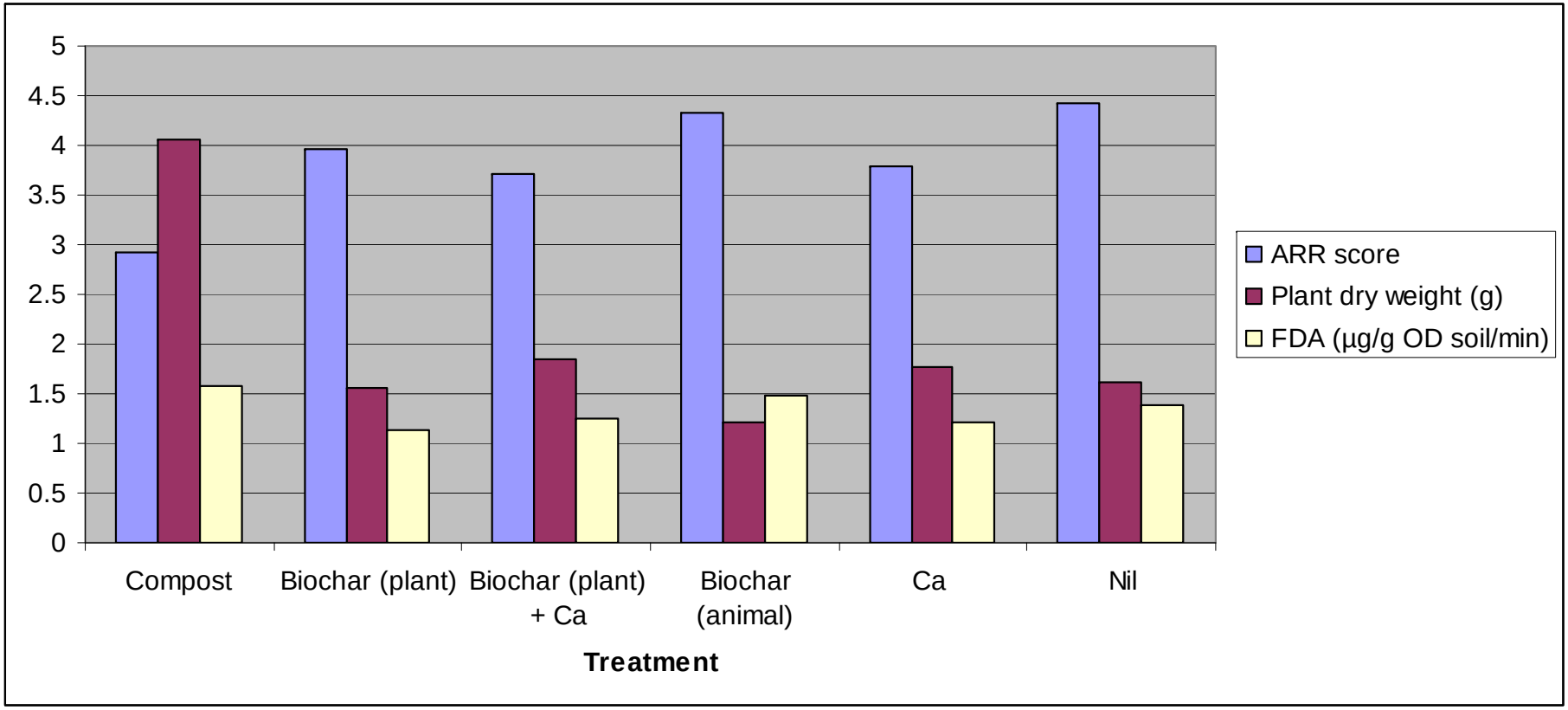

Figure 10-2: The effect of organic amendments on Aphanomyces root rot (ARR) of beans in traditional potting media - pot trial 2

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Wu J, Joergensen RG, Pommerening B, Chaussod R, Brookes PC (1990) Measurement of soil microbial biomass by fumigation-extraction - An automated procedure. Soil Biology and Biochemistry 22:1167-1169

11. Technology transfer

International Conferences

Organisation of Nematologists of Tropical America 43rd Annual Conference Coimbra Portugal 4-8 September 2011.

Pattison AB, Jovicich E, Bagshaw J, Cobon J and Kukulies T (2011) Soil nematodes as indicators of the sustainability of minimum tillage in tropical vegetable systems. XLIII Organisation of Nematologists of Tropical America, 4-8 September, 2011 Coimbra, Portugal

National conferences

International Symposium on 'Soil Organic Matter and Compost in Horticulture', 4-7 April, 2011 held in Adelaide. The papers have been peer reviewed and revised and are pending publication in Acta Horticulturae.

Donovan NJ, Saleh F, Chan KY, Eldridge SM, Fahey D, Muirhead L, Meszaros I, Barchia I (in press) Use of garden organic compost in a long-term vegetable field trial: biological soil health. Acta Horticulturae: International Symposium on Organic Matter Management & Compost Use in Horticulture, Adelaide, Australia, 4-7th April 2011

Eldridge SM, Donovan NJ, Saleh F, Barchia I, Chan KY (in press) Changes in soil quality over 5 consecutive vegetable crops following the application of garden organics compost. Acta Horticulturae: International Symposium on Organic Matter Management & Compost Use in Horticulture, Adelaide, Australia, 4-7th April 2011

Pattison A, Geense P, Kukulies, T and Forsyth L. (In Press) Can soil nematode community structure be used to indicate soil carbon dynamics in horticultural systems? *Acta Horticulturae*, International Symposium on Organic Matter Management & Compost Use in Horticulture, Adelaide, Australia, 4-7th April 2011.

Jovicich E, Pattison T, Kukulies T, Forsyth L, Heisswolf S and Le Feurve P (2011) Minimum tillage and semi-permanent bed effects on organic carbon and other soil properties in a zucchini production system in the dry tropics. International Symposium on Organic Matter Management & Compost Use in Horticulture, Adelaide, Australia, 4-7th April 2011

6th Australasian Soilborne Disease Symposium 9-11 August 2010, Twin Waters, Queensland

Bell MJ, **Pattison AB** and Harper S (2010) Sustainable farming systems – key management factors and their application in subtropical and tropical vegetable production systems6th Australasian Soilborne Disease Symposium 9-11 August 2010, Twin Waters , Queensland

Grower presentations and field days

Research findings from the NSW long-term field trial have been presented to industry during the following seminars:

Pattison AB. A presentation was given to Bowen vegetable growers and industry providers at the Precision Horticulture Workshop on Vegetable Production Systems and Soil Health, Bowen Qld Australia, 18th September 2013

Pattison AB. Vegetable Production Systems and Soi lHealth EnviroVeg Field Days, Gatton Qld, Australia 21st August 2013

Donovan NJ. Use of garden organic compost in a long-term vegetable field trial. Hawkesbury Nepean Microscope Club. University of Western Sydney, NSW, Australia 24th April 2012

Pattison AB & Jovicich E. Vegetable Soil Health Field Walk Ayr Research Facility and Bowen Research Facility, Qld, Australia 17 & 18th April 2012

Donovan NJ. Use of garden organic compost in a long-term vegetable field trial. Vegetable Soil and Crop Health Seminar. Ayr Research Facility and Bowen Research Facility, Qld, Australia 17 & 18th April 2012

Vegetable Plant and Soil Health Field Walk, Bowen Research Station, December 15 2010

Soil Management Seminars, Bowen and Ayr Research Stations, April 28-29, 2011

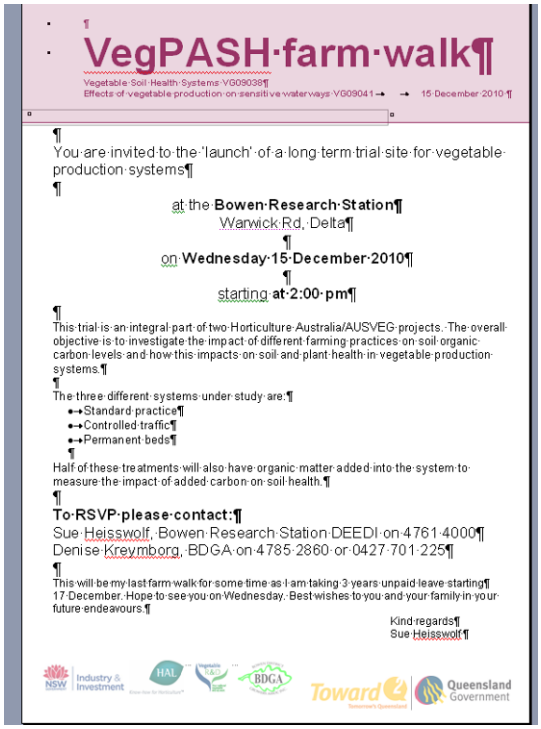
Soil Management Impacts on Soil Health, Bowen Research Station, September 3, 2012

Nerida Donovan will be presenting results from the NSW DPI CROA long-term field trial at an AORA (Australian Organics Recycling Association) breakfast meeting to be held at Mamre Homestead, Orchard Hills on 16th October 2013.

A field day is planned for late spring 2013. The focus of the field day is 'Compost and Soil Health' and is being coordinated by Darren Fahey (NSW Market and Industry Development Officer, AORA) with assistance from the NSW DPI project team. Nerida Donovan and Simon Eldridge will be presenting findings from the NSW long-term field trial. A tour of the ANL compost production facility is included in the proposed itinerary.

Components of the work undertaken by the NSW DPI team also forms part of a PhD study being undertaken by project team member Fadi Saleh who is enrolled with the Faculty of Agriculture and Environment at the University of Sydney. The PhD thesis is titled 'Identifying and quantifying the potential benefits and mode of action of soil amendments for the suppression of soil borne diseases in 2 different pathosystems' and submission is planned for 2014. The PhD project supervisors are Professor David Guest from the University of Sydney and Nerida Donovan and Rosalie Daniel from NSW DPI. Refereed journal papers are in preparation on the long-term field trial,

although further work is needed via the PhD project before the pot trial data can be published.



VegPASH farm walk

Vegetable Soil Health Systems VG09036
Effects of vegetable production on sensitive waterways VG09041 → 15 December 2010

You are invited to the 'launch' of a long term trial site for vegetable production systems

at the **Bowen Research Station**
Warwick Rd, Delta

on **Wednesday 15 December 2010**

starting **at 2:00 pm**

This trial is an integral part of two Horticulture Australia/AUSVEG projects. The overall objective is to investigate the impact of different farming practices on soil organic carbon levels and how this impacts on soil and plant health in vegetable production systems.

The three different systems under study are:

- Standard practice
- Controlled traffic
- Permanent beds

Half of these treatments will also have organic matter added into the system to measure the impact of added carbon on soil health.

To RSVP please contact:
Sue Heisswolf, Bowen Research Station DEEDI on 4761 4000
Denise Kreymborg, BDGA on 4785 2860 or 0427 701 225

This will be my last farm walk for some time as I am taking 3 years unpaid leave starting 17 December. Hope to see you on Wednesday. Best wishes to you and your family in your future endeavours.

Kind regards
Sue Heisswolf

Sensitive waterways project
Soil health project

Industry experience wanted at soil management seminars

BOWEN	AYR
Wednesday April 28	Thursday April 29
2pm to 5pm	2pm to 5pm
Bowen Research Station	Ayr Research Station
Warwick Road, Delta	343 Old Clare Road

The Bowen and Burdekin vegetable cropping areas will be the focus of two new soil research projects

One project is about the *Environmental effects of vegetable production on sensitive waterways focusing on efficient crop nutrition*. The other is exploring *Vegetable soil health systems and their impact on soil borne disease*. These two projects are closely interlinked and we are planning to set up a long term research trial at the Bowen Research Station.

We would like your opinion on the most valuable areas of study for these projects and invite you to participate at the soil management seminars.

To RSVP or for more information
please contact Sue Heisswolf at Bowen Research Station on 4761 4000
Department of Employment Economic Development and Innovation

HAL | Vegetable R&D | Queensland Government

Seminar agenda

2:00pm	Introductions – Sue Heisswolf, Bowen Research Station
Presentations	
2:15pm	Environmental effects of vegetable production on sensitive waterways – the focus is on nutrient management at the paddock level Steve Harper, Gatton Research Station
2:30pm	Vegetable soil health systems and their impact on soil borne disease Tony Pattison, South Johnstone Research Station
2:45pm	Controlled traffic farming in vegetables – proposed project – Sue Heisswolf
3:00pm	Organic carbon and soil structure – Nick O'Halloran, DPI Victoria
Industry discussions	
3:15pm	Improving soil management for vegetable crops in the region – facilitated session Led by John Bagshaw, Bundaberg Research Station and Sue Heisswolf What is the vegetable industry doing already? What issues do we best focus on within the two projects? What practical outputs or information would help industry improve their soil management?
4:00pm	Designing the long term trial for the Bowen Research Station – facilitated session Led by John Bagshaw and Sue Heisswolf
4:45pm	What next?
5:00pm	Seminar close

2

Field Walk
Soil management: impacts on soil health

Date:	Monday, 3 September, 2012
Time:	3.00 – 4.30 pm
Venue:	Bowen Research Station 45 Warwick Rd, Bowen

Join us for a short field walk on soil management practices and their impacts on soil health.

The field walk will include:

CTF and tillage practice impact on soil health Long term soil health trial site looking at CTF and tillage practices. Funded by HAL.

On farm CTF system
Results from on farm CTF demonstration site including soil quality data and economics of CTF versus non CTF system.

Rainfall simulator demonstration
Demonstration of the impact of rainfall on soil with different management practices.

RSVP by Friday 31 August 2012 to:
Sarah Limpus (07) 4761 4000 or sarah.limpus@daff.qld.gov.au

CARING FOR OUR COUNTRY | Queensland Government

Newsletters

Five newsletters have been produced and disseminated within this project

1. VegPASH Issue 5

VegPASH news

Vegetable Soil Health Systems VG09038
Effects of vegetable production on sensitive waterways VG09041 Issue 5 August 2010

Compiled by

John Bagshaw
Tony Pattison
Sue Heisswolf
DEEDI – Agri-science Queensland

If you do not wish to receive future updates, or to change your email or postal address, please contact John Bagshaw on 07 4132 5547 or email john.bagshaw@deedi.qld.gov.au

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Soil health hypothesis
Project activities:
North Queensland
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New South Wales
Project personnel
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Upcoming events

These projects were facilitated by HAL in partnership with AUSVEG and were funded by the vegetable levy. The Australian Government provides matched funding for all HAL's R&D activities. State government funding for the project has been provided through the Queensland Department of Employment, Economic Development and Innovation and the NSW Department of Industry and Investment.

Welcome

This is the first newsletter of two new projects that will continue the VegPASH newsletter series. The two new projects are:

- **vegetable soil health systems for overcoming limitations causing soil borne diseases (VG09038), and**
- **environmental effects of vegetable production on sensitive waterways (VG09041)**

The soil health project will build on the results of the previous project which identified key soil health issues for vegetable production around Australia. These issues revolved around soil organic carbon (SOC) management, nutrient management and retaining good soil structure on clay soils. Two long term field trials plus a series of trials on co-operating growers' properties are planned. This work aims to develop and validate strategies for improving SOC levels and soil health as well as investigate the ability of high-carbon soils to suppress soil diseases in vegetable crops. We also hope to discover more about how soil biology can help improve vegetable production systems.

The sensitive waterways project will investigate the risk of off-site nutrient movement at a farm block scale and gather nutrient budget data on a range of vegetable crops. It also aims to develop broader processes for addressing industry and community concerns associated with nutrient and soil losses in vegetable production. The work involves detailed studies of nutrient use and movement on four sites in Queensland. It will link in with a long term field trial in Queensland to measure impacts of increased SOC on off-site nutrient movement risks.

In this first issue we will focus on progress with the soil health project.

Suppressing soil-borne diseases – our hypothesis

We believe that SOC and its management is the key for improving soil health as SOC is central to most physical, chemical and biological soil properties. In the previous project we looked at soil health indicators to measure these soil properties and their relationship with the different pools of carbon in the soil.

In general, as SOC increases, so does the amount of organic nitrogen that can be converted into plant-available mineral forms (ammonium and nitrate) by soil microbes.

In sandy soils and soils high in iron oxides, SOC makes an important contribution to the cation exchange capacity (CEC), a measure of the soil's ability to hold the nutrient cations of calcium, magnesium and potassium.

Soil microbes require a carbon source for energy. Thus, increasing SOC is generally associated with increasing microbial activity in the soil. This in turn increases the rate at which nutrients are released from the soil organic matter. SOC also helps to bind soil particles into aggregates, which helps maintain soil porosity, water infiltration and soil aeration. Stable aggregates also resist compaction caused by tillage and machinery and resist erosion.

Our strategy is to investigate how best to increase and maintain SOC and to increase our understanding of how this might impact on disease suppression in soils as part of an integrated approach to managing soil health.

There are still many unknowns. Our hypothesis is that sound management of SOC leads to a healthier soil which is turn in more likely to result in healthy crops by:

- promoting plant vigour and giving plants a natural ability to resist soil diseases
- increasing activity and diversity of soil microbes which compete with soil disease organisms for space and nutrients. Some soil organisms actively feed on plant disease species.

What next?

In the next newsletter we will focus on the sensitive waterways project. We will also update you on progress with soil health project including the long-term replicated trial work and the grower demonstration sites.

Recent events

- 19th World Congress of Soil Science *Soil Solutions for a Changing World*, Brisbane Australia 1-6 August, 2010 http://www.19wcss.org.au/index.php
- 6th Australasian Soilborne Diseases Symposium (6th ASDS) Twin Waters on Queensland's Sunshine Coast 9-11th August 2010 http://www.asds6.org/

Upcoming events

- International Symposium on Organic matter management and compost use in horticulture, 4-7 April 2011, University of Adelaide, Australia http://compost-for-horticulture.com/

North Queensland. Planning for a long-term field trial is underway at the Bowen Research Station. This trial will investigate the most efficient way of increasing and/or maintaining SOC in vegetable production in the Dry Tropics. The aim of the trial is to monitor how and to what extent reduced tillage and addition of organic materials change soil health properties over time and if these changes are linked to the ability of soil to suppress soil borne diseases. As part of the sensitive waterways project, we will also be measuring on risk of off-site nutrient loss in the different systems under investigation in this long term trial.

South-East Queensland. Compaction is a problem on the heavy clay soils in the Lockyer Valley. A field trial is planned to investigate changes in soil condition under controlled traffic for vegetable production and how this might impact on soil borne disease problems.

New South Wales. A long-term field trial using compost and different phosphorus rates has been established in NSW at the Centre for Recycled Organic Agriculture. This trial has been running for 5 years so some soil properties have already changed. The trial provides an ideal opportunity to assess how these changes may relate to the suppression of soil borne diseases. A lettuce crop was recently grown on the site and is currently being evaluated (Figure 1).

Figure 1: Yin Chan, Agronomist with the Dept of Industry & Investment, Richmond, evaluates lettuce from a long term compost trial in New South Wales

Project personnel for the soil health project

In Queensland, the project team members from the Department of Employment, Economic Development & Innovation are:

North Queensland: Tony Pattison (Nematologist and project leader), Sue Heisswolf (Horticulturist) - Bowen; Elio Jovicich (Horticulturist) - Ayr.

South-east Queensland: John Duff (Plant-pathologist) - Gatton, Jenny Cobon (Nematologist) & Wayne O'Neill (Nematologist) - Brisbane, John Bagshaw (Extension Horticulturist) - Bundaberg.

In New South Wales, the project team members from the Department of Industry & Investment are:

Nerida Donovan (Plant pathologist and NSW leader) & Fadi Saleh (Plant-pathologist) – EMAI Camden and Yin Chan (Agronomist) – Richmond

NEW - Soil health manual

A soil health manual has been completed and is now available on the web at http://www.dpi.qld.gov.au. Just type 'soil health for vegetable production' into the search box. The manual, authored by DEEDI and DERM staff, provides information about soil type specific constraints and how to deal with them, how to measure soil conditions and interpret them and hints on good horticultural practice for improved soil health. The manual is primarily aimed at vegetable industry agronomists and other service providers, and also vegetable growers.

2. VegPASH Issue 6

VegPASH news

Vegetable Soil Health Systems VG09038
Effects of vegetable production on sensitive waterways VG09041 Issue 6 December 2010

Compiled by

John Bagshaw
Tony Pattison
DEEDI – Agri-science Queensland

If you do not wish to receive future updates, or to change your email or postal address, please contact John Bagshaw on 07 4132 5547 or email john.bagshaw@deedi.qld.gov.au

Contents

Sensitive waterways project.
Long-term soil health trial Bowen, Queensland.
Sugarcane-vegetable rotation trial, Bundaberg, Queensland.

These projects were facilitated by HAL in partnership with AUSVEG and were funded by the vegetable levy. The Australian Government provides matched funding for all HAL's R&D activities. State government funding for the project has been provided through the Queensland Department of Employment, Economic Development and Innovation and the NSW Department of Industry and Investment.

Welcome to the sixth edition of the VegPASH newsletter which features the sensitive waterways project (VG09041). AUSVEG funded this project because of increasing concern by communities about the effects of intensive agriculture on surrounding environments. The project has two components: one in Queensland and one at Watson's Creek in Victoria.

Sensitive waterways project - Queensland

This component of the project aims to explore fertiliser use efficiency on vegetable farms. More efficient fertiliser use is good for the grower and good for the environment. There is limited Australian scientific data on the amount of nutrients different vegetable crops remove from the soil, so it is difficult to know what an efficient application of fertiliser really is for these crops. Ideally sufficient fertiliser is added to replace only that removed by a crop.

The project team are sampling key vegetable crops from farms around the State to gather local crop nutrient removal information. Growers will then be able to assess their fertiliser regimes against likely crop nutrient removal figures for these crops. Another output from the work will be a practical guide to on-farm partial nutrient budgeting for those that wish to develop their own nutrient budgets.

A range of crops have already been sampled, including lettuce, broccoli, cauliflower, celery and cabbage in the Lockyer Valley, and capsicum, sweet corn, rockmelon and zucchini in North Queensland. Further sampling is planned for the North Queensland, Bundaberg and Lockyer Valley regions over the next two years. Recent flooding in the Lockyer Valley will impact on planned activities there.

In addition to crop sampling, the project team plans to use a long-term trial site at Bowen and two trial sites in the Lockyer Valley to do full nutrient budgeting for several key vegetable crops. A full nutrient budget measures all pathways of nutrient movement, including inputs, crop uptake and losses from the farming system.

The project team assesses a potential trial site. From left, Phil Moody, Steve Harper, Robert Premier, Sarah Limpus and Luke Jackson take in Julie O'Halloran's wisdom.

DEEDI project team members are:

Steve Harper (Gatton), Sue Heisswolf (Bowen),, John Bagshaw (Bundaberg), Sarah Limpus (Gatton), Julie O'Halloran, (Gatton), Elio Jovicich (Ayr) and Tony Pattison (South Johnstone). And from DERM, Phil Moody (Brisbane).

Sensitive waterways project - Victoria

Another region of community concern is at Watson's Creek in Victoria. Reducing the inflow of nutrients, silt and chemicals into this creek has become important as the creek empties into Western Port Bay, a marine National Park of world significance. A local environmental group (Mornington Peninsula and Western Port Biosphere Reserve Foundation) is working with all local stakeholders including vegetable growers to improve the creek's water quality. The Foundation has also been subcontracted to conduct a case study on how the vegetable industry can work with the community.

Dr Robert Premier, a project collaborator and consultant from Melbourne,is working with growers in the area to establish sustainable practices for vegetable farming.

Project Team Movements

Sue Heiscwolf at Bowen DEEDI is taking three years leave without pay. She will be replaced by **Sarah Limpus** who starts at Bowen at the end of January 2011. Sarah previously worked for DEEDI at Gatton Research Station.

Upcoming events

- International Symposium on Organic Matter Management and Compost Use in Horticulture, 4-7 April 2011, University of Adelaide, Australia http://compost-for-horticulture.com
- AUSVEG 2011, 14-16 April 2011, Gebel-Citigate Hotel, Brisbane, Australia http://ausveg.com.au/events/ausvegconvention.htm

Some interesting reading

- Controlled traffic farming in intensive vegetables: does it pay? (factsheet).
- Controlling machinery traffic in vegetables. What it means for the farming system (factsheet).

To view both of these, go to: www.healthywaterways.org/HealthyCountry/Resources/GustainableLandManagementResources.aspx

Acronyms

DEEDI – Department of Employment, Economic Development & Innovation, Queensland.

DERM – Department of Environment & Resource Management, Queensland

GPS – Global Positioning System

I&I NSW – Industry & Investment NSW (previously Dept Agriculture)

The outputs of this component of the project will be a guide to community engagement on sensitive waterway issues, and a good practice guide for vegetable farming in catchments with sensitive waterways.

Long-term trial - Bowen Qld

A long-term field trial has just started at Bowen Research Station. The main aim of this trial will be to compare the effect of three different vegetable growing systems on crop productivity and soil health. The systems are conventional practice, controlled traffic and permanent bed. Each system will have split plots with compost added /no compost added.

The **conventional practice** is annual cultivation for bed preparation, with a cover crop grown over summer. Drip irrigation and plastic mulch is replaced annually. The **controlled traffic system** uses GPS to ensure tractor wheels always drive in the same wheel tracks year after year. Each year the beds (not wheel tracks) are cultivated strategically, reformed and drip irrigation lines and plastic mulch re-laid. The **permanent bed system** also uses controlled traffic but the beds are maintained for up to 5 years before being renovated. Instead of using plastic mulch, a cover crop is grown and mulched on the bed during this time with the vegetable crop planted into the mulch.

The trial will test how well each treatment increases and sustains organic carbon levels resulting from regularly added organic matter and reduced tillage. The assumption is that increased soil organic carbon (SOC) will improve general soil health (physical, chemical and biological properties), enable better nutrient management, improve crop productivity and decrease the risk of offsite nutrient movement.

Sue Heisswolf explains the Bowen Research Station trial (background, currently under forage sorghum) to local growers and agribusiness staff.

This trial will provide good data on how the different cropping systems will affect SOC (and other soil characteristics) over time. The trial will also be used to conduct full nutrient budget studies for the sensitive waterways project.

A farm walk launch was conducted by project staff for local vegetable growers and agribusiness in December 2010 to raise awareness of the long-term trial.

Impact of management practices on productivity and off-site water quality in farming systems with sugarcane and intensive vegetable rotations.

This trial at Bundaberg, Qld is being conducted by DEEDI Plant Sciences staff and is funded by the Reef Rescue program. Its primary aim is to quantify the effects of different sugarcane-vegetable rotations on offsite water quality. However it is also investigating soil health and nutrition with these different systems. It complements our two projects hence we have close collaboration with the project. It started in Spring 2010 and will finish 2013.

The selected vegetable rotation treatments compare conventional tropical vegetable production (cultivation and use of drip irrigation and plastic mulch) with some newer practices such as minimum tillage, planting into a trash blanket, using an interrow green mulch (millet), and improved nutrient management. The crop sequence in the horticulture phase between cane crops is spring capsicum followed by autumn zucchini.

Measurements will include crop yield and quality, soil health, crop nutrient uptake and nutrients in leached and runoff water.

3. VegPASH Issue 7

Department of Employment, Economic Development and Innovation

VegPASH news

Vegetable Soil Health Systems VG09038
Effects of vegetable production on sensitive waterways VG09041

Issue 7 July 2011

Compiled by
John Bagshaw and Tony Pattison
DEEDI – Agri-science Queensland

Contents
- NSW long-term compost trial results
- Bowen trial update
- Tillage – effects on soil biology

If you do not wish to receive future updates, or to change your email or postal address, please contact John Bagshaw on 07 4132 5547 or email John.bagshaw@deedi.qld.gov.au

These projects were facilitated by HAL in partnership with AUSVEG and were funded by the vegetable levy. The Australian Government provides matched funding for all HAL's R&D activities. State government funding for the project has been provided through the Queensland Department of Employment, Economic Development and Innovation and the NSW Department of Primary Industries.

NSW long-term trial results

A long-term field trial was established in 2005 at Camden in the Sydney Basin by Dr Yin Chan (now retired from NSW Department of Primary Industries) as part of the Centre for Recycled Organics in Agriculture (CROA). The aim of the trial is to evaluate the effect of garden organic compost on vegetable production and soil quality compared to conventional practice, and under low and high soil phosphorus (P) status.

Nerida Donovan (centre) and project staff harvest the tenth crop from the trial site.

The compost is made from green waste sourced from households and municipal areas. These products are currently used in urban or landscaping situations in the Sydney Basin but intensive vegetable production is an alternative market worth investigating.

The trial is made up of seven treatments: garden organic compost, conventional practice (frequent tillage, fertiliser and poultry manure) and a mixture of compost and inorganic fertiliser, all replicated at high and low soil P, plus a no-input control.

Compost was applied once at the beginning of the trial and again before the sixth crop (125 dry t/ha/application). To date ten crops have been grown and a third application of compost is scheduled for this year.

Results from the field trial to date show that applying compost has significantly improved a number of soil properties, including soil carbon, cation exchange capacity, exchangeable cations and structural stability, compared with conventional farming practice. Applying compost also increased soil biological properties in the first crop but the benefit was diminished in subsequent crops. However, the soil biological response was greater following the second compost application than the first compost application.

Yields for the compost treatments were similar or higher than in soils under conventional farming practice at both low and high P soil conditions. Other results of the field trial show that the high levels of extractable soil P currently found in vegetable farms around Sydney are not necessary for maintaining productivity. These high P levels are excessive and of environmental concern due to increased potential for off-site water pollution.

Future work as part of the current project (VG09038) is to expand the assessment of soil biological indicators and investigate the potential for pathogen suppression.

Update on Bowen soil health trial

We are testing the impact of permanent beds, organic surface mulch, controlled traffic, reduced tillage and compost on soil health and crop yield in a field trial at Bowen. The permanent bed treatments were formed in August 2010, compost treatments were applied in September 2010 at 15 t/ha (made from sugar cane/chicken manure base and donated by a local grower). Sorghum was planted over the whole trial in September, slashed in January 2011, then killed off with herbicide in March and slashed again. During April, the sorghum mulch was incorporated into the soil in the conventional and controlled traffic treatments.

NSW Primary Industries · HAL · Vegetable R&D · Queensland Government

Upcoming events

XXIX International Horticultural Congress, Brisbane, Australia, August 2014. www.ihc2014.org/

Some interesting reading

Dordas C (2008) Role of nutrients in controlling plant diseases in sustainable agriculture. A review. *Agronomy for Sustainable Development* 28, 33–46.

Morris NL, Miller PCH, JH Orson and Froud-Williams RJ (2010) The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment. A review. *Soil and Tillage Research* 108, 1–15.

Roger-Estrade J, Anger C, Bertrand M and Richard G (2010) Tillage and soil ecology: Partners for sustainable agriculture. *Soil and Tillage Research* 111, 33–40.

Strosser E (2010) Methods for determination of labile soil organic matter: An overview. *Journal of Agrobiology* 27, 49–60.

VegPASH News now on-line

Check out current and previous issues at: www.dpi.qld.gov.au/30_20298.htm

Topsoil was sampled in November 2010 to provide base data on physical, chemical and biological soil condition in the trial site. There were no differences in soil properties among treatments at this stage. Deep soil samples were taken in January 2011. The trial site endured heavy rains and waterlogging for most of the summer.

Conventional practice (left) and no-till permanent beds with organic mulch (right) are being compared in the trial.

Conventional and controlled traffic plots were cultivated again during May 2011 (with more tillage in the conventional plots), but sorghum mulch was left on the soil surface of the permanent bed plots. At the end of May, beds were formed and drip irrigation tape and black polyethylene mulch were laid in the conventional and controlled traffic treatments. The first capsicum and zucchini crops were planted in June 2011, and soil was again sampled at planting. Full Stop® units were installed soon after planting to monitor nutrient leaching from the root zone.

The impact of tillage on soil biology

New research around the world is investigating the impacts of tillage on soil biology. A recent review by Roger-Estrade et al. (2010) suggests that more intensive tillage systems reduce the abundance, diversity and community structure of soil organisms. Community structure indicates the number of predators (that is, organisms that prey on other organisms) in a living soil community. High community structure means soil disease organisms are more likely to be suppressed by other soil organisms.

Inversion tillage	Tined implements	Reduced tillage	No tillage
• mould board plough • disc plough • rotary hoe	• deep ripping • tined implements	• permanent beds • strip tillage along planting beds only	• permanent beds • trash-planting

Intensive tillage → Moderate tillage → No tillage

Intensive tillage can damage soil biology by:
- causing physical injury to organisms due to compaction
- destroying organism habitat
- exposing organisms to sun and dryness
- exposing larger soil organisms to predation from birds when soil is turned
- reducing longer-term availability of organic matter as a food source for soil organisms.

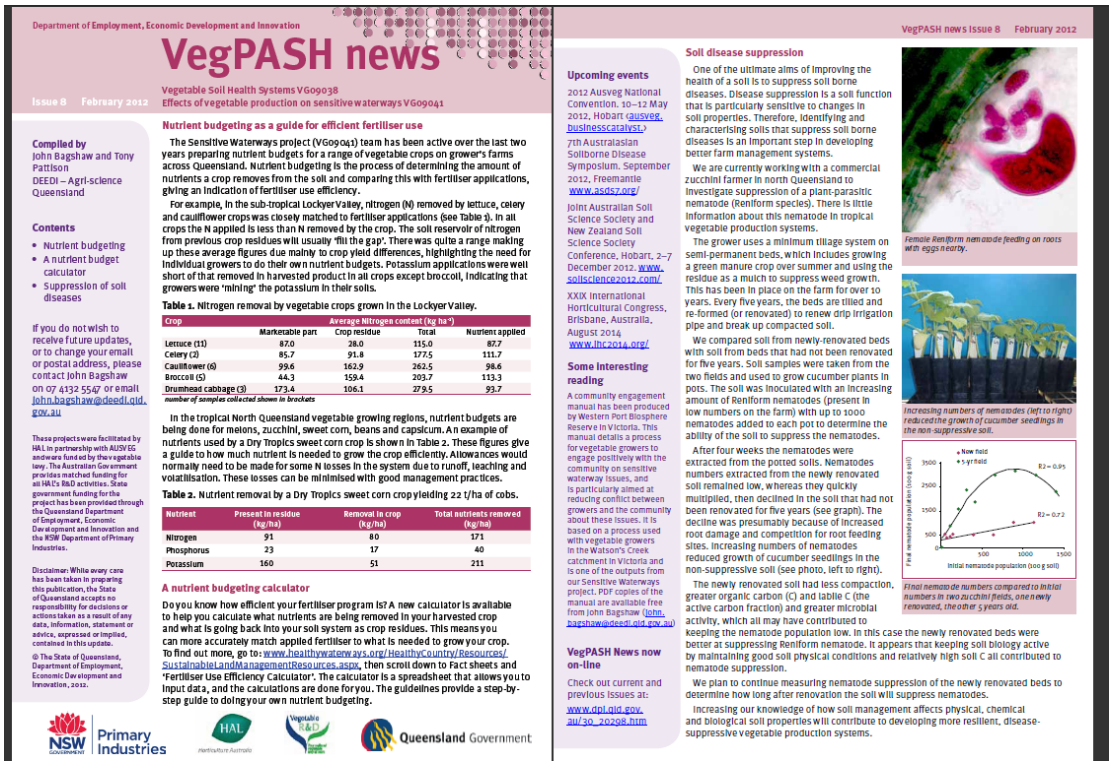
Tillage promotes rapid but short-lived decomposition of organic matter and release of nutrients, particularly nitrogen and carbon. This may give a temporary increase in biological activity but depletes the soil of organic carbon and reduces biological activity in the longer term.

Reduced tillage, where organic matter is left on the soil surface, creates a more stable environment that encourages greater soil biodiversity to develop. More organisms are involved in decomposing organic matter allowing a greater opportunity for predators to increase in the soil (higher community structure). Soil scientists theorise that decomposing organic matter favors the survival of predators by providing alternative prey, reducing competition, providing shelter and, in general, providing a more favorable environment. This contributes to better suppression of soil diseases.

Some strategic tillage may be needed to mix organic matter accumulating on the soil surface, to break up hard pans and to improve drainage. Strategic tillage means only cultivating when and where necessary.

So what impact does infrequent strategic tillage have on soil biology? Does a single tillage operation reduce soil biological community structure or can soils with a resilient and diverse biology quickly recover? These questions are currently being investigated in trials with the vegetable soil health project (VG09038).

4. VegPASH Issue 8



Department of Employment, Economic Development and Innovation

VegPASH news

Vegetable Soil Health Systems VG09038
Effects of vegetable production on sensitive waterways VG09041

Issue 8 February 2012

Compiled by
John Bagshaw and Tony Pattison
DEEDI – Agri-science Queensland

Contents
- Nutrient budgeting
- A nutrient budget calculator
- Suppression of soil diseases

If you do not wish to receive future updates, or to change your email or postal address, please contact John Bagshaw on 07 4132 5547 or email John.bagshaw@deedi.qld.gov.au

These projects were facilitated by HAL in partnership with AUSVEG and were funded by the vegetable levy. The Australian Government provides matched funding for all HAL's R&D activities. State government funding for the project has been provided through the Queensland Department of Employment, Economic Development and Innovation and the NSW Department of Primary Industries.

Nutrient budgeting as a guide for efficient fertiliser use

The Sensitive Waterways project (VG09041) team has been active over the last two years preparing nutrient budgets for a range of vegetable crops on grower's farms across Queensland. Nutrient budgeting is the process of determining the amount of nutrients a crop removes from the soil and comparing this with fertiliser applications, giving an indication of fertiliser use efficiency.

For example, in the sub-tropical Lockyer Valley, nitrogen (N) removed by lettuce, celery and cauliflower crops was closely matched to fertiliser applications (see Table 1). In all crops the N applied is less than N removed by the crop. The soil reservoir of nitrogen from previous crop residues will usually 'fill the gap'. There was quite a range making up these average figures due mainly to crop yield differences, highlighting the need for individual growers to do their own nutrient budgets. Potassium applications were well short of that removed in harvested product in all crops except broccoli, indicating that growers were 'mining' the potassium in their soils.

Table 1. Nitrogen removal by vegetable crops grown in the Lockyer Valley.

Crop	Average Nitrogen content (kg ha⁻¹)			
	Marketable part	Crop residue	Total	Nutrient applied
Lettuce (11)	87.0	28.0	115.0	87.7
Celery (2)	85.7	91.8	177.5	111.7
Cauliflower (6)	99.6	162.9	262.5	98.6
Broccoli (5)	44.3	159.4	203.7	113.3
Drumhead cabbage (3)	173.4	106.1	279.5	93.7

number of samples collected shown in brackets

In the tropical North Queensland vegetable growing regions, nutrient budgets are being done for melons, zucchini, sweet corn, beans and capsicum. An example of nutrients used by a Dry Tropics sweet corn crop is shown in Table 2. These figures give a guide to how much nutrient is needed to grow the crop efficiently. Allowances would normally need to be made for some N losses in the system due to runoff, leaching and volatilisation. These losses can be minimised with good management practices.

Table 2. Nutrient removal by a Dry Tropics sweet corn crop yielding 22 t/ha of cobs.

Nutrient	Present in residue (kg/ha)	Removal in crop (kg/ha)	Total nutrients removed (kg/ha)
Nitrogen	91	80	171
Phosphorus	23	17	40
Potassium	160	51	211

A nutrient budgeting calculator

Do you know how efficient your fertiliser program is? A new calculator is available to help you calculate what nutrients are being removed in your harvested crop and what is going back into your soil system as crop residues. This means you can more accurately match applied fertiliser to what is needed to grow your crop. To find out more, go to: www.healthywaterways.org/HealthyCountry/Resources/SustainableLandManagementResources.aspx, then scroll down to Fact sheets and 'Fertiliser Use Efficiency Calculator'. The calculator is a spreadsheet that allows you to input data, and the calculations are done for you. The guidelines provide a step-by-step guide to doing your own nutrient budgeting.

NSW Primary Industries · HAL · Vegetable R&D · Queensland Government

Upcoming events

2012 Ausveg National Convention. 10–12 May 2012, Hobart (ausveg.businesscatalyst.)

7th Australasian Soilborne Disease Symposium. September 2012, Freemantle www.asds7.org/

Joint Australian Soil Science Society and New Zealand Soil Science Society Conference, Hobart, 2–7 December 2012. www.soilscience2012.com/

XXIX International Horticultural Congress, Brisbane, Australia, August 2014 www.ihc2014.org/

Some interesting reading

A community engagement manual has been produced by Western Port Biosphere Reserve in Victoria. This manual details a process for vegetable growers to engage positively with the community on sensitive waterway issues, and is particularly aimed at reducing conflict between growers and the community about these issues. It is based on a process used with vegetable growers in the Watson's Creek catchment in Victoria and is one of the outputs from our Sensitive Waterways project. PDF copies of the manual are available free from John Bagshaw (John.bagshaw@deedi.qld.gov.au)

VegPASH News now on-line

Check out current and previous issues at: www.dpi.qld.gov.au/30_20298.htm

Soil disease suppression

One of the ultimate aims of improving the health of a soil is to suppress soil borne diseases. Disease suppression is a soil function that is particularly sensitive to changes in soil properties. Therefore, identifying and characterising soils that suppress soil borne diseases is an important step in developing better farm management systems.

Female Reniform nematode feeding on roots with eggs nearby.

We are currently working with a commercial zucchini farmer in north Queensland to investigate suppression of a plant-parasitic nematode (Reniform species). There is little information about this nematode in tropical vegetable production systems.

The grower uses a minimum tillage system on semi-permanent beds, which includes growing a green manure crop over summer and using the residue as a mulch to suppress weed growth. This has been in place on the farm for over 10 years. Every five years, the beds are tilled and re-formed (or renovated) to renew drip irrigation pipe and break up compacted soil.

Increasing numbers of nematodes (left to right) reduced the growth of cucumber seedlings in the non-suppressive soil.

We compared soil from newly-renovated beds with soil from beds that had not been renovated for five years. Soil samples were taken from the two fields and used to grow cucumber plants in pots. The soil was inoculated with an increasing amount of Reniform nematodes (present in low numbers on the farm) with up to 1000 nematodes added to each pot to determine the ability of the soil to suppress the nematodes.

After four weeks the nematodes were extracted from the potted soils. Nematodes numbers extracted from the newly renovated soil remained low, whereas they quickly multiplied, then declined in the soil that had not been renovated for five years (see graph). The decline was presumably because of increased root damage and competition for root feeding sites. Increasing numbers of nematodes reduced growth of cucumber seedlings in the non-suppressive soil (see photo, left to right).

Final nematode numbers compared to initial numbers in two zucchini fields, one newly renovated, the other 5 years old.

The newly renovated soil had less compaction, greater organic carbon (C) and labile C (the active carbon fraction) and greater microbial activity, which all may have contributed to keeping the nematode population low. In this case the newly renovated beds were better at suppressing Reniform nematode. It appears that keeping soil biology active by maintaining good soil physical conditions and relatively high soil C all contributed to nematode suppression.

We plan to continue measuring nematode suppression of the newly renovated beds to determine how long after renovation the soil will suppress nematodes.

Increasing our knowledge of how soil management affects physical, chemical and biological soil properties will contribute to developing more resilient, disease-suppressive vegetable production systems.

5. VegPASH Issue 9

VegPASH news

Vegetable Soil Health Systems VG09038
Effects of vegetable production on sensitive waterways VG09041 **Issue 9 February 2013**

Compiled by

Tony Pattison
Sarah Limpus
DAFF – Agri-science Queensland

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Contents

Minimum tillage comes good in Bowen

Benchmarking soil health practices report now out

These projects have been funded by HAL using the vegetable industry levy and matched funds from the Australian Government. State government funding for the project has been provided through the Queensland Department of Agriculture, Fisheries and Forestry and the NSW Department of Primary Industries.

Minimum tillage comes good at Bowen

Vegetable production typically uses aggressive tillage operations with little organic matter input. This can lead to declining soil health, fertility and reduced crop yields. Vegetable growers are seeking alternative methods of production that allow soil improvements, without compromising production or quality. Permanent beds with organic mulch are an alternative to existing systems that rely on "plasticulture" (Fig 1).

Fig 1: Conventional intensive tillage "plasticulture" system and permanent bed systems with no soil disturbance and sorghum mulch before planting zucchini and capsicum at Bowen

A trial established at Bowen in 2011 compares a conventional, intensive tillage system to an undisturbed permanent bed system with organic mulch. In the first year of the trial, yields of capsicum were reduced in the permanent bed system by 70% and in zucchini by 30%, compared to traditional management. Soil compaction was determined to be the major soil constraint, followed by water and nutrient management. Modifications to the permanent bed and management practices were needed for this system to be commercial.

In the following year, 2012, the same conventional intensive tillage system was compared with modified permanent bed systems involving minimal soil disturbance produced by zone tillage (Fig 2) and a hybrid system, which had permanent beds and organic matter covered by plastic mulch. The narrow zone tillage was performed using a wavy disc cultivator along the row where vegetable seedlings were transplanted. This had the effect of reducing soil resistance in the top 15 cm by approximately 30%.

Fig 2: Zone tillage on permanent beds using wavy disc coulters on permanent beds in the trial at Bowen in 2012.

At end of the 2012 season there was no significant yield difference among the tillage systems in either capsicums (Fig 3) or zucchinis. Comparing the permanent beds systems between the years, the 2012 modified system using zone tillage and improved water and nutrient management, had a 52% increase in the marketable yield of zucchini and 228% increase in the marketable yield of capsicums. Comparing input use in 2012 only, the permanent beds used approximately 20% less nitrogen compared to intensive tillage but required double the amount of irrigation water.

This demonstrates that a permanent bed system, which uses organic mulch and zone tillage, has the potential for equivalent production to conventional intensive systems. However, it requires specific farming equipment and management to overcome constraints like soil compaction. Future refinements to the permanent bed system are possible, like the use of biodegradable mulch to reduce irrigation water requirements.

Upcoming events

First International Control Traffic Farming Conference, 26-27 February 2013, Toowoomba, Queensland
http://www.actfa.net/

2013 Ausveg National Convention, 30 May – 1 June 2013, Gold Coast, Queensland
http://ausveg.com.au/events/Convention%202013/ausvegconvention_copy.htm

19th Australasian Plant Pathology Conference, 25 – 28 November 2013, Auckland, New Zealand
http://www.apps2013.co.nz/

XXIX International Horticultural Congress, Brisbane, Australia, August 2014
http://www.ihc2014.org/

Some interesting reading

Microbial ecology in sustainable agroecosystems.

Tanya Cheeke, David Coleman, Diana Wall, Published by Taylor & Francis Ltd UK

This book brings together soil ecologists, microbial ecologists, and agroecologists working globally to demonstrate how research in soil ecology can contribute to the long-term sustainability of agricultural systems. Key areas of research include; agriculture, biodiversity, ecosystem services, integrated soil ecology research, and policy. Topics include: a broad range of soil microbial processes, inputs by soil microorganisms into farming systems, the importance of arbuscular mycorrhizal fungi, the benefits and environmental problems associated with the use of genetically modified crops, the incorporation of soil ecological theory into agricultural practice to improve productivity and sustainability The contributors cover the diversity and complexity of microbial activity and interactions in soil systems and the many ways in which microorganisms may be manipulated and managed to improve the crop functions.

VegPASH News now on-line.
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www.dpi.qld.gov.au/30_20298.htm

Permanent bed + zone tillage | Permanent bed + zone tillage + polyethylene mulch | Conventional intensive tillage

Fig 3 Capsicum plants 96 days after transplanting in three tillage systems in the field trial at Bowen in 2012

VG11034 - Benchmarking Uptake of Soil Health Practices Report Now Out

Following concerns that poor soil health management could result in large losses to productivity, increased disease and long-term damage to catchments, Horticulture Australia Limited (HAL) identified soil health as a priority for the vegetable industry. Subsequently, a vegetable industry soil health program was implemented, comprising three projects. A review of the soil health program was commissioned by HAL. The main findings of the review and vegetable grower surveys, undertaken by Dr Gordon Rogers (Applied Horticultural Research P/L) include:

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

More information from Dr. Gordon Rogers, Applied Horticultural Research P/L. For vegetable levy paying growers, final reports are available on the AUSVEG website www.ausveg.com.au or contact AUSVEG on (03) 9822 0388 or email info@ausveg.com.au. For non levy paying members the report is available from HAL http://www.horticulture.com.au/reports/order_a_final_report.asp

12. Recommendations

The general recommendations from the soil health research conducted in vegetable production systems include:

- Soil health issues are typically regional problems and therefore, need to have regional solutions. For example, the method for overcoming declining soil health in north Queensland is the use of minimum tillage, organic mulch systems because land is readily available, but the climate constrains the production season. Around the Sydney basin, where land availability is a limiting factor, the use of compost and recycled organics may be more appropriate.
- Changes to soil properties take time to manifest themselves, requiring longer term research activities. Small incremental changes appeared after one year, but longer term changes over 5-10 years are required to validate the systems.
- The testing and validation of vegetable production systems needs to be flexible to allow changes to be made in response to new information as it becomes available. This was evident in the minimum tillage trials with the use of zone tillage, management of water and nutrients and compost use in order to advance the production system.
- As vegetable growers reduce their inputs and develop more sustainable systems, soil biological process become more important to enhance disease suppression and nutrient recycling. However, a greater understanding of how soil biology contributes to the functioning of the soil is required, with particular emphasis on understanding the functions of organisms in vegetable cropping systems.

North Queensland trial work

Contrasts of conventional and minimum tillage vegetable systems for tropical areas and the operations required in the different systems are presented below:

Conventional		Minimum tillage	
Activity	**Time of the year**	**Activity**	**Time of the year**
Previous crop is killed with herbicide and/or slashed. Polyethylene mulch and drip tape are removed from the field and disposed.	When harvests finish, sometime before November	Previous crop is slashed and soil is tilled with disc and tyned implements. Soil amendments are applied to the soil to overcome a deficiency or to correct an imbalance	Sometime before October and previous to Year 1 of the bed renovation cycle
Field may be tilled, crop residues incorporated into the soil, and a summer cover crop (e.g. sorghum) may be planted.	October - November	Planting beds are formed with GPS. Drip tape/tubing is placed below soil surface. Paths for driving farm equipments are not tilled. Controlled traffic farming in all activities.	October - November
Cover crop or natural grasses and weeds may be left to grow during the wet season.	February - March	Dry pre-plant fertiliser may be incorporated in beds based on soil analysis to improve dry matter production of the summer cover crop	October - November
Cover crop is slashed and cover crop, grass, weeds or crop residues are incorporated into the soil to a depth of 20-25 cm with disc implements. Time is allowed so plant residues fully decompose in the soil.	February - April. Wet conditions determine when this can be done.	Sorghum is planted in double rows along the edges of the bed	October - November
The whole field is tilled with disc and tyned implements and rotary hoe. Blocks are cross ripped, several times and soil crumbs are reduced in size. Amendments are applied to the soil to overcome any nutrient deficiency or to correct an nutrient or pH imbalance	February - April	Subsurface drip system can be used to water and fertilise sorghum if required during dry periods early in the summer	November – February
Optimal soil moisture conditions for soil preparation may only exist after timely rain events	February - April	Sorghum is slashed and mulched during the summer but to an extent that will allow rapid regrowth. Wet conditions will limit the number of cuts.	January – February
Planting beds are made with a bed former. Dry pre-plant fertiliser is incorporated in beds based on soil analysis results and projected requirements of future crop	After March and targeting planting dates (e.g. from April to August)	Sorghum is slashed and mulched and regrowth is sprayed with glyphosate. Herbicide sprays applied as needed depending on weed population.	February – March

Conventional		Minimum tillage	
Activity	**Time of the year**	**Activity**	**Time of the year**
Polyethylene mulch and drip tape are laid on beds	Targeted planting dates and subject to optimal weather conditions (e.g. from April to August)	Zone tillage is practiced just before transplanting with two wavy disc coulters in one or two rows per bed (depending on plant arrangement of future crop) and a crumble roller pulled behind.	Targeted planting dates and subject to optimal weather conditions (e.g. from April to August)
Transplanting is done with a conventional water wheel planter	Target planting dates (e.g. from April to August)	Optimal soil moisture conditions for zone tillage are achieved through irrigation or exist after timely rain events	Same as before
Irrigation may be scheduled based on soil moisture readings or other plant/soil assessments, and given every 2-4 days apart	During the crop growing season	Polyethylene or better, biodegradable mulch can be laid on beds with sorghum residue. A pass of a roller (also pulled behind the wavy disc coulters) may be needed to flatten stems in plant residues. A conventional poly mulch laying implement with minimum modifications can be used. Optimal soil moisture conditions are required	Same as before
Soluble fertilisers are delivered through drip once weekly	During the crop growing season	A conventional water wheel planter with increased water supplied to seedlings than in conventional systems can be used. A starter fertiliser can be dissolved in the water tank of the planter.	Same as before
Weed management mostly confined to inter-rows	During the crop growing season	Irrigation may be scheduled based on soil moisture readings or other plant/soil assessments, every 1-3 days apart	During the crop growing season
Pest and diseases are monitored and control measures are used. Preventive spray programs are also implemented	During the crop growing season	Soluble fertilisers are delivered through drip once or twice weekly	During the crop growing season
At the end of harvesting the crop is killed with herbicide and/or slashed. With early season crops a second crop may be planted on the same beds. Polyethylene mulch and drip tape are removed from the field and disposed.	When harvests finish, sometime before November	Weed management is done with selective herbicides and inter-row shield spraying. This is critical early in the crop season. Available herbicides with short withholding periods are limited. Shade from fast growing canopies will help suppress weeds. Emergence of weeds will be reduced in areas with no tillage	During the crop growing season
Beds may be tilled and a planted cover crop or natural grasses and weeds may be left to grow during the wet summer season.	October - November	Pest and diseases are monitored and control measures are used. Preventive spray programs are also implemented	During the crop growing season
Soil will be tilled again in the following year to form new planting beds	February - April. Wet conditions determine when this can	At the end of harvesting the crop, plants are slashed and herbicides are applied if needed. In beds with polyethylene mulch, the plastic can be removed by	Sometime before October to prepare beds for Year 2 of the bed renovation

Conventional		Minimum tillage	
Activity	**Time of the year**	**Activity**	**Time of the year**
	be done.	loosening soil on the sides of the bed (without disturbing the soil of the whole bed) in order to rollup the poly mulch. A subsequent pass with a bed former may be required. This would not be needed when biodegradable mulch is used.	cycle
		Sorghum is planted in double rows along and close to the edges of the bed as the next summer cover crop. The Year 2 of the bed renovation cycle begins. Planting beds may not be renovated (completely tilled) for three or more years.	October - November

Sydney basin trial work

Specific recommendations and findings identified by the NSW DPI CROA compost vegetable field trial include:

- **A repeat large application of blended green waste compost can be economical over 10 vegetable crops when capsicum (bell pepper) is the first crop planted after application.**

  Capsicum responded to the repeat compost application by achieving near maximum yield. Two, one-off applications of compost at 62.5 dry t/ha and 125 dry t/ha application rates, each followed by 5 vegetable crops with supplementary N fertiliser in later crops, achieved a BCR of 2.63 and 3.33 respectively, when compared to conventional farmer practice in the Sydney Basin.

- **A large application of compost (125 dry t/ha) can result in significant (*P<0.05*) improvements in soil quality parameters (physical, chemical, biology) compared to conventional production practices, immediately after application.**

  These measures include percentage water stable aggregates, carbon %, CEC %, pH, cations, nutrients and soil microbial biomass.

- **No tillage or reduced tillage cultivation systems may help to prolong the soil quality benefits of compost application.**

  The extent of difference in the measured values for soil quality parameters between the compost treatment and conventional farmer practice was generally found to decrease over successive crops. This was thought to be associated with the decrease in soil organic matter content and the physical destruction of soil structure associated with intensive tillage using the rotary hoe.

- **Repeat, large compost applications may be needed to promote sustained differences in soil biological properties.**

  The second application of compost was found to have a more pronounced and prolonged effect on soil biology (as reflected in microbial biomass C) than was found following the first application of compost. This may reflect a conditioning of the soil biology from the first application, allowing a greater response to further compost inputs.

- **Compost applications result in fertiliser savings although crop monitoring and supplementary fertiliser may be needed to maintain productivity.**

  Nitrogen availability indexes of 0.10 of Total N for blended green waste compost and 0.25 of total N for chicken manure were found to ensure adequate supply of N for the first crop following compost application, if the compost was incorporated into the soil immediately after spreading. Supplementary inorganic N was generally required for the compost treatments after the first crop onwards.

- **Available P levels in the soil should serve as an effective limit for the application of composts and other organics to minimise environmental harm to water quality**.

  Phosphorus levels in soil also need to be monitored in fields receiving large applications of blended compost. The 2nd application of compost in the field trial had almost double the total P and Colwell P levels of the first compost, and this is believed to be due to the manufacturer increasing the chicken manure component from 10 to 20% in the compost. The second large compost application produced elevated soil Colwell P levels in the order of 250 mg/kg.

- **Potassium from full compost treatment (125 dry t/ha) was sufficient to meet the requirements of 5 successive vegetable crops in the Sydney environment.**

  Although it was evident from the soil test results that a significant amount of the soil exchangeable K was lost from the compost treatment soils by leaching over the time of these 5 crops.

13. Acknowledgements

Project personnel

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John Lewis (Clare, Qld)

Greg and Kevin Silvia (Valla, NSW)

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Nufarm

Agrichem

South Pacific Seeds

Seminis

Australian Native Landscapes

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14. Appendices

14.1. Lessons learnt from minimum tillage trials

Comments on crops' production in the 2011 trial at Bowen

- Compared to plants grown with intensive tillage and plasticulture, plants in the 2011 permanent beds grew at a slower rate after transplanting and had lower yields.
- Reduced plant growth and yield in no tilled beds were greater in capsicum than in zucchini.
- In the 2011 season, irrigation given to permanent beds was 60% greater than in polyethylene-mulched beds. Fertiliser rates were the same in all tillage treatments but low (30%) compared to rates in commercial farms.
- Fruit yields with intensive tillage and plasticulture were acceptable in capsicums and zucchini considering the low fertilisation rates (all delivered via drip with no pre-plant).
- The addition of compost did not increase yields in the first year.
- Sorghum mulch and shading provided by the large zucchini leaves provided good weed control over the planting beds. However, there were more problems with broadleaf weeds in permanent beds with capsicum.

Summary of problems identified with permanent beds in the 2011 trial season at Bowen and proposed changes that were later implemented in 2012.

Problems observed in 2011	**Possibly caused by**	**due to**	**Proposed change practice to minimise problem**
Difficult transplanting and establishment of seedlings. Slow initial plant growth.	Compaction on top soil	Heavy rain in summer; suboptimal soil preparation; poor soil structure; non specific transplanter	Zone tillage and/or use no-till transplanter
Reduced growth of vegetable crop	Suboptimal soil moisture	Irrigation was increased by +60% compared to polyethylene mulched beds. Low frequency of irrigation events	Increase irrigation frequency with management based on soil moisture measurements. Test if a film mulch can be laid over permanent beds with plant residues
Reduced growth of vegetable crop	Suboptimal nutrient availability	No pre-plant fertiliser and low nutrient rates delivered through fertigation	Increase fertilisation rates and frequency of delivery
Reduced growth of vegetable crop	Suboptimal soil temperature and/or allelopathy.	Sorghum residue as mulch	System which includes permanent beds and polyethylene or biodegradable film mulch

Comments on crops' production in the 2012 trial at Bowen

- Plants in permanent beds with or without polyethylene film mulch grew at a similar rate and produced comparable fruit yield and fruit quality than plants grown with intensive tillage and plasticulture.
- Zone tillage overcame soil compaction on permanent beds and improved the stand establishment of zucchini and capsicum. Zone tillage also made possible the use of a conventional waterwheel planter.
- In the 2012 season, water used with irrigation in permanent beds was 2.4 times greater than in polyethylene-mulched beds, but the volume was reduced to 1.4 times greater when the permanent bed had polyethylene film mulch. With permanent beds all fertilisers were delivered via drip. Fertiliser rates were the same or slightly lower in permanent beds than in plants grown with intensive tillage and plasticulture.
- The addition of compost after the second year, gave indication of fruit quality improvement.
- Early management of weeds is especially important with capsicums because herbicides can have long withholding periods until harvest. This issue makes the production of a thick mulch residue even more important for capsicums.
- Good weed management in permanent beds was achieved when using black polyethylene film mulch. However it would be more practical and environmentally sustainable to use biodegradable film mulch. This is being tested in 2013.

Summary of problems identified with permanent beds in the 2012 trial season at Bowen and proposed changes that are being implemented in 2013.

Problems observed in 2012	**Possibly caused by**	**due to**	**Proposed change practice to minimise problem**
Reduced growth of cover crop	No fertilisation and irrigation after planting	Low nutrient levels left after the vegetable crop. Sorghum planting in November and rainfall events delayed to early January.	Fertigate sorghum to produce larger biomass which will help manage weeds and produce organic matter
Difficulty transplanting along zone-tilled area with conventional waterwheel planter	Dry hard soil crumbles along zone-tilled area	Low soil moisture; zone till practiced too early before transplanting; poor soil structure; non specific transplanter	Zone tillage practiced before transplanting. Use a crumble roller behind the zone till machinery. Manage soil moisture with irrigation. Increase water flow in conventional planter. (addressed during 2012)
Stubble from cover crop clogs the transplanter	Non specific transplanter	Larger roots and stems in cover crop. Soil too wet.	Modify transplanter by adding a cutting disc that would cut the dead roots and stems of the cover crop into smaller sections.

Problems observed in 2012	Possibly caused by	due to	Proposed change practice to minimise problem
Difficulty managing broadleaf weeds	Rainfall during dry season and along zone tillage bed area. Excessive irrigation wets top of the planting bed.	Soil moisture and soil disturbance	Not critical with zucchini but weed problems may appear with capsicums because herbicides can have long withholding periods until harvest. Machinery modification that could cover tilled zone with plant residues. Use of biodegradable black film mulch.
Compost not placed near the crop root zone	Compost broadcasted on top of beds before mulching cover crop	Identification of appropriate machinery that can incorporate compost with minimum tillage	Specific compost dispenser under the bed or that applied in bands along the bed surface and it is zone tilled thereafter
Removal of polyethylene mulch require manual labour	If tillage is not implemented, the edges of polyethylene film remain under the soil	With time, compacted soil firmly holds the poly film to the sides of the bed	Test the use of a biodegradable film mulch on permanent beds, which will eventually decompose to nontoxic components in the field