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prepared by	Dr Chris Dorahy, Dr Anabelle Tulin (Philippines research component) and Simon Eldridge [A] (Component leader and Australian research component) [1]
co-authors/ contributors/ collaborators	Dr Agustin Mercado, Juanita Salvani, Carmelito Lapoot, Valeriana Justo, Lorena Duna, Dr Nelda Gonzaga, Cecille Marie Quinones, Rolland Rallos, Michelle Rañises, Marciana Galambao, Dr Yin Chan [A] and Dr Nerida Donovan [A]
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[1] *The component was initially led by Dr Yin Chan with Philippines activities managed by Drs Chris Dorahy and Annabelle Tulin. Simon Eldridge took over the management of the Australian component and administration of the overall project in mid-2010.*

[A] *Australian component*

Contents

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- Visayas State University (VSU)
- Northern Mindanao Integrated Agricultural Research Centre (NOMIARC)
- Misamis Oriental State College of Agricultural and Technology (MOSCAT)
- University of Los Bãnos (UPLB)
- NSW Department of Primary Industries (NSW DPI)
- Ableblue Pty Ltd

2 Executive summary

An integrated research program was developed which involved assessment, field research, communication and capacity building activities in the Southern Philippine regions. Key outcomes of the Philippines work included the benchmarking of the soil fertility status and management practices through soil surveys and testing, farmer surveys and nutrient omission trials. Nitrogen and phosphorus were found to be the key nutrients controlling vegetable yields in most soils. A useful approach for calculating the cost of nutrients in fertilisers was developed to allow farmers to compare the price of nutrients in different inorganic and organic fertilisers. Further carefully designed field trial research is recommended to allow the fine tuning of recommendations for optimal N, P and K fertiliser applications for the main vegetable crops in these regions.

Capacity building was a highlight of this program and activities included; the participation of four Philippine soil scientists at the World Congress of Soil Science in Brisbane and visiting the NSW DPI field trial site at Camden in 2010, two ACIAR funded professional development studies to Australia, the completion of one MSc and three BSc student projects, training for VSU Lab Technician (Cynthia Goddoy) at the NSW DPI soils laboratory in Wollongbar, and ACIAR funded laboratory upgrades for the VSU soils laboratory. In addition, there were a series of farmer technical forums and training workshops to help extend basic soil science skills to advisors and farmers in Southern Philippines regions, and these attracted a lot of interest and high attendances from the communities.

A key message arising from the project is that recycled organics alone are unlikely to provide all the nutrients required to achieve the productivity required to meet the food demands of the Philippines. Nevertheless, they have great potential to be used in conjunction with inorganic fertilisers to increase fertiliser use efficiency, provide some nutrients, and in some instances help to improve crop yields by improving soil quality. Sustainable soil fertility and nutrient management entails understanding soil fertility status, matching inputs to outputs and monitoring soil conditions to ensure nutrients do not accumulate or diminish over time.

The ACIAR funding from this project allowed the NSW DPI long-term compost vegetable field trial in the Sydney Basin at Camden, NSW to be extended for another five crops following a repeat application of blended green waste compost. This work has generated some important findings relating to compost use in intensive vegetable production systems. These include;

Capsicum responded to compost applications by achieving near maximum yield. Two one off applications of compost at 60 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 benefit: cost ratio of 2.63 and 3.33 respectively, when compared to farmer practices. Most of the economic benefit was due to the yield improvement for capsicum. The larger application of compost (125 dry t/ha) resulted in significant (*$P<0.05$*) improvements in soil quality parameters (physical, chemical, biology) immediately after application compared to the farmer practices. These measures included percentage water stable aggregates, carbon %, CEC %, pH, cations, nutrients and soil microbial biomass. Some of these improvements (e.g. soil structure) dissipated over time with successive crops and associated tillage. Resultant elevated soil P levels eventually provide an environmental upper limit for the number of such large compost applications.

Recent increases in the promotion of organic farming in the Philippines means that it is important to conduct further research comparing vegetable production between organic, inorganic, and integrated mixed organic – inorganic systems, to provide guidance for farmers to help them to optimise food production with their available resources.

3 Background

Providing higher economic returns per unit area and developing new export markets for high value crops in the Philippines had been identified as a priority by the Philippine Government and the Australian Centre for International Agricultural Research (ACIAR) as a means of increasing economic growth and improving the standard of living of people living in rural areas. In the southern Philippines, vegetables are one of the primary crops for regions 8 (Eastern Visayas), 10 (Northern Mindanao) and 11 (Davao) and have significant potential for expanding vegetable production. Moreover, vegetables were and still are seen as strategically important to the Australian Government, whereby efforts to improve the livelihoods of the populations could contribute to improving geo-political stability in the region. However, a number of barriers existed to achieving these objectives including: a lack of grower expertise in soil management and crop agronomy; high incidence of pests and diseases; lack of developed markets and value chains for horticultural produce; and political/economic constraints, such as limited capital/resources and insecurity of land tenure. To address these issues, ACIAR developed two large multi-disciplinary programs (HORT/2007/066, vegetables and -067, fruit). The aim of this component was to develop integrated soil and crop nutrient management in vegetable crops in the southern Philippines and Australia to facilitate more profitable and sustainable vegetable production.

A scoping study in the Philippines, undertaken by Dr Keerthisinghe (ACIAR), Dr Menz (ANU) and Dr Dorahy (ableblue) in November 2007 had identified key issues with respect to soil and crop nutrient management in vegetable production systems in Northern and Eastern Mindanao and the Eastern Visayas (Leyte). Issues included declining soil fertility; high cost of inorganic fertilizers and a lack of grower capital; a shift towards more “organic” production; availability of organic materials; lack of information and training; and the widespread prevalence of soil-borne diseases. Common problems encountered by the vegetable farmers are inherent poor soil fertility and productivity, lack of appropriate technologies, improper water and soil conservation management and other production factors such as fertilizers and limited capital. The inadequate knowledge in soil and crop nutrient management of vegetable farmers leads to improper allocation of limited financial resources that could result in financial risk, poor soil fertility management and low productivity.

Therefore, a need existed to assess the current soil fertility status in soils used for vegetable production, quantify the rates of nutrient removal from these systems (mass balances) and develop strategies for matching nutrient inputs to crop and soil requirement through the judicious and integrated application of inorganic and organic fertilizers. When organic fertilizers are used, there is a need to quantify the availability and types of materials, evaluate the treatment and stabilization technologies (e. g. composting) and determine how they can be applied in conjunction with inorganic fertilizers to optimize productivity and profitability. Dissemination and training activities are also required to promote the outcomes and maximize benefits to growers.

In the Philippines, the main issue is that conventional inorganic fertilisers are expensive and growers are looking towards alternative inputs such as composts, manures and crop residues to improve/ maintain soil fertility. Likewise there is a need to improve the understanding of how inputs (both inorganic and organics) should be managed in these systems. This issue is of equal relevance to the vegetable industry in NSW where there is a need to improve nutrient management by vegetable growers to manage inputs more efficiently. This was highlighted by research from the NSW DPI research team, which demonstrated vegetable soils typically contain excessive concentrations of phosphorus and are structurally degraded (Chan *et al*. 2007a).

Research (2005-2008) at the Centre for Recycled Organics in Agriculture (CROA) at Camden, NSW had demonstrated that compost addition can sustain vegetable yields and improve soil quality, whilst avoiding some of the phosphorus accumulation observed in conventional production systems (Chan *et al.* 2010). Therefore this work is important for helping to change nutrient management practices and develop new markets for recovered organic resources in NSW. However, the benefits of organic inputs on soil quality (soil physical, chemical and biological properties) can take a number of years to be fully expressed. Thus this new ACIAR project (component 1) presented a unique opportunity to extend the vegetable-compost field experiment at CROA by a further 3 years or more and to further define long-term benefits of using compost in vegetable production systems. It also allowed an economic analysis to be carried out on the full 10 vegetable crops to compare compost treatments with the standard farmer practice. This work has direct benefits for NSW vegetable growers as implementing the research outcomes should help NSW and Australian vegetable growers to manage organic inputs more effectively to ensure production is both profitable and sustainable over the long term. The CROA experiment was also seen as a valuable training resource to assist professional development for Philippine and Australian scientists associated with the project.

4 Objectives

The aim of this Component was to develop integrated soil and crop nutrient management in vegetable crops in the southern Philippines and Australia so that vegetable production could be more profitable and sustainable. The objectives underlying this aim and the activities for achieving them are summarised below:

Objective 1. Define current soil fertility status and management practices

Activities

1.1. Identify soil fertility constraints by: interviewing farmers regarding current fertiliser and nutrient management practices; undertaking a baseline survey of soil fertility in key vegetable producing districts and on representative soil types of Mindanao and Leyte.

1.2. Evaluate alternative nutrient inputs (abundance, nutrient supply, cost, effect on soil physical, chemical and biological properties).

1.3 Evaluate treatment/ value adding options (e.g. composting).

Objective 2. Develop more productive nutrient management systems for vegetables

Activities

2.1. Calculate nutrient mass balances for different crop management systems.

2.2. Refine how inputs are used (rates, timing, crops)

2.3. Identify alternative crop rotation options (e.g. Agro-forestry, tree crops, intercropping)

2.4. Refine nutrient management strategies for protected cropping systems

2.5. Undertake Cost-Benefit Analysis of different management options and identify constraints to adoption

2.6. Monitor incidence and severity of pests and diseases in response to different treatment options

2.7. Continue current field research experiment at CROA to evaluate the longer-term benefits of using compost in vegetable production systems

2.8. Establish 2–3 demonstration trials in commercial fields in key vegetable growing regions of New South Wales to demonstrate the benefits of using compost and disseminate Component findings to date.

Objective 3. Encourage adoption of best management practices.

Activities

3.1. Develop best management practice guideline and other education and extension material for optimal soil/ water/ crop management in vegetables.

3.2. Establish 4–5 field trials on leading grower farms in the Philippines

3.3. Involve farmers at the Component inception point to facilitate strong participatory research.

3.4. Link with ICRAF/ Landcare and Components 2-5 of HORT 2007/066 to conduct Farmer Field Schools.

Objective 4. Build scientific research capacity of collaborating staff in the Philippines to promote the development of more sustainable and profitable vegetable production in the Philippines

Activities

4.1. Train Component staff in new methods of agricultural and soil research.

4.2. Use the CROA field site as a training resource for visiting collaborating scientists from the Philippines.

4.3. Selected component team members to visit the CROA field research experiment to learn about Australian R&D and vegetable production systems in Australia.

4.4. Selected Component team members to attend/ present at relevant national and international conferences.

5 Methodology

The region, locations and collaborators responsible for undertaking the Philippine activities documented under the following objectives were:

Region	Locations	Collaborators
Leyte	Ormoc	• Dr Anabelle Tulin (VSU)
Mindanao	Claveria	• Dr Agustin Mercado Jr. (ICRAF)
	Lanpatan, Bukidnon	• Ms Juanita Salvani & Mr Carmelito Lapoot (NOMIARC, DA-RFU X)
	Kapatagan	• Ms Valeriana P. Justo (UPLB), Kapatagen United Farmers Association

The methodologies for achieving the objectives of the component are below. The Philippine methodologies are presented in more detail in pages 8 to 10 in the report provided by DrsTulin and Dorahy (Attachment 1).

Objective 1. Define current soil fertility status and management practices

1.1. Identify soil fertility constraints by: interviewing farmers regarding current fertiliser and nutrient management practices; undertaking a baseline survey of soil fertility in key vegetable producing districts and on representative soil types of Mindanao and Leyte.

Farmers were interviewed regarding current fertiliser and nutrient management practices. This followed the protocols developed and used in the Participatory Assessment undertaken in association with ACIAR project CP/2005/075 – 'Integrated soil and crop management for rehabilitation of vegetable production in the tsunami-affected areas of NAD province, Indonesia' (AIAT *et al.* 2007). A baseline survey of soil fertility in key vegetable producing districts and on representative soil types of Mindanao and Leyte was undertaken. Data collected included, soil physical, chemical and biological properties as well as information on site history and production system. These surveys followed protocols previously developed by Chan *et al.* (2007a) and other ACIAR projects (e.g. Foale 1987; Cameron, 1999). The questionnaire used is in Appendix 1 Tulin and Dorahy (2013), attached.

1.2. Evaluate alternative nutrient inputs (abundance, nutrient supply, cost, effect on soil physical, chemical and biological properties).

The availability and characteristics of potential alternative inputs to systems (e.g. crop residues, animal manures, rice straw, caribou) were examined following the protocols and framework developed by Dorahy *et al.* (2005) and Chan *et al.* (2007b).

1.3 Evaluate treatment/ value adding options (e.g. composting).

Options for treating, stabilising and adding value to these organic materials (e.g. composting) were also evaluated. This complemented existing work being undertaken at Visayas State University, Leyte and ICRAF, Mindanao, with respect to vermi-composting.

Objective 2. Develop more productive nutrient management systems for vegetables

2.1. Calculate nutrient mass balances for different crop management systems.

Mass balance studies (nutrient inputs/ outputs) were undertaken for selected treatments over the duration of field experiments. Mass balance = Soil nutrient status + nutrient inputs - nutrients removed in produce. This was based on current nutrient management practices described by farmers and predictions on typical nutrient uptake and removal patterns based on published data for the typical yields described. See attachment 1, page 20-23).

2.2. Refine how inputs are used (rates, timing, crops)

Optimum application rates and timing were determined based on information generated from Activity 2.1 to ensure that application rates of inorganic and organic fertilisers replenish nutrients removed from the system and meet the nutrient requirements of subsequent crops.

2.3. Identify alternative crop rotation options (e.g. Legumes, agro-forestry, tree crops, intercropping)

Less emphasis was placed on this strategy, although different crop rotations (e.g. *Brassicaceae* after *Solanaceae*) and the potential for bio-fumigation were evaluated in collaboration with HORT/2007/066/3 (Bacterial wilt of solanaceous crops) to reduce the incidence and severity of pests and diseases.

2.4. Refine nutrient management strategies for protected cropping systems

An experiment was undertaken at VSU in collaboration with HORT/2007/066/2 to develop strategies for refining nitrogen management strategies under protected cropping systems. Two Bachelor of Science Undergraduate student projects (Sabijon and Gabitano) were completed in conjunction with this experiment to examine nitrogen cycling from open field and protected cropping situations, as well as rates and forms (organic and inorganic) of nitrogen. See attachment (Tulin and Dorahy. 2013).

2.5. Undertake cost benefit analysis of different management options and identify constraints to adoption

An inventory of costs associated with all inputs was collected for all management options evaluated in the field trials. Similarly, treatment effects on returns associated with improved vegetable yield and quality were documented and the information was used to construct cost/ benefit analyses for different management options over the duration of the 3 year field trials. This work was not finalised.

2.6. Monitor incidence and severity of pests and diseases in response to different treatment options

In collaboration with HORT/2007/066/3, assessments were made on the effects of different treatment options on the incidence and severity of soil-borne pests and diseases. Many of the field sites for HORT/2007/066/1&3 were in close proximity to each other (e.g. Kapatagan, Mindanao), whilst Mr Carmelito Lapoot and Ms Vale Justo were members of both components. This facilitated linkages between the Components and made it possible to share common field sites and collaborate with common farmer groups.

2.7. Continue current field research experiment at CROA to evaluate the longer-term benefits of using compost in vegetable production systems

This component built upon 3 years of research already undertaken at NSW DPI's CROA site, which quantified the benefits of using compost in vegetable cropping systems over 5 consecutive vegetable crops (Chan *et al.* 2007a). The ACIAR funding allowed the field trial at CROA to continue for another set of 5 consecutive crops between October 2008 and June 2011 (capsicum, broccoli, lettuce, cabbage, sweet corn) following a repeat application of garden organics compost to the compost treatments (125 dry t/ha to full compost treatment and 62.5 dry t/ha to the mixed compost treatments). This allowed the completion of monitoring of crop yield and quality measures, as well as soil quality (physical, chemical and biological properties) for these crops.

Composite soil samples to 30cm at the end of crop 10 allowed additional assessments of resultant soil carbon and nutrient stores from the treatments following 10 crops. An economic analysis was conducted on this system over 10 crops, to compare the compost and mixed treatments with the current farmer practices. For a detailed description of the methodology for the CROA compost vegetable field trial, refer to Appendix 1.

The CROA field trial site was also used as a training site for Philippine scientists who visited the site, where they could see the experimental design and set up in the field and equipment used for monitoring soil moisture using GBugs ® and Time domain reflectometry (TDR) and soil compaction using a penetrometer.

2.8. Establish 2–3 demonstration trials in commercial fields in key vegetable growing regions of New South Wales to demonstrate the benefits of using compost and disseminate component findings.

A demonstration trial was established by the District Horticulturalist at the NSW DPI demonstration farm (University of Western Sydney, Richmond) between May and December 2010. Two 50m x 20m adjacent blocks were established. One plot received a 60 dry t/ha application of garden organics compost which was rotary hoed into the soil to 10cm. The other plot was fertilised according to farmer practice. The compost plot received only urea fertiliser at half the N loading of the farmer practice treatment. A crop of cabbages was planted late in September and harvested mid December 2010.

Given the dramatic response to compost by the capsicum crop experienced in the CROA field trial, it was decided that a 2nd demonstration trial using capsicum would be attempted by the District Horticulturalist at the NSW DPI demonstration farm at the University of Western Sydney (UWS), Richmond. An application of 100 dry t/ha of garden organics compost was applied to the compost block on December 7, 2011 and incorporated into the soil. Unfortunately record levels of rainfall occurred over the weeks and months following compost application, which resulted in localised flooding and erosion across the demonstration site, essentially ruining this trial.

At present (i.e. Winter 2013), the project is attempting to set up a demonstration trial to demonstrate the findings from this project to farmers with some Horticulture Australia Limted (HAL) and commercial industry funding at a market gardener farmer site in Western Sydney.

Objective 3. Encourage adoption of best management practices.

3.1. Develop best management practice guidelines and other education and extension material for optimal soil and crop nutrient management in vegetables.

The outcomes from the research and demonstration activities in the Philippines and Australia, were used to assist the development of a best management practice guideline and other education and extension material for optimising soil fertility and plant nutrition in vegetable cropping systems. Supporting material such as Technotes and NSW DPI “Primefacts” were also used. This used protocols used by NSW collaborators for successfully disseminating outcomes from previous research projects (e.g. Dorahy *et al.* 2006 and Dorahy *et al.* 2007). It was planned that this material would be written so that it would be a useful resource for both Philippine and Australian vegetable growers.

A training program was developed called Extension Advisor Training workshop With Excellent Learning Lessons (EATWELL). This was developed using material from experiments, Australian education material and other material such as from the International Plant Nutrition Institute Soil fertility manual (IPNI, www.ipni.net).

The EATWELL workshop was held at the Northern Mindanao Integrated Agricultural Research Centre (NOMIARC), Department of Agricultural Regional Field Unit 10 (DARFU X), Malaybalay, Mindanao, Philippines. ACIAR Project SCNM/2007/066/1, 22-26 August, 2011

The specific aims of the EATWELL Workshop were to: i) Train EATWELL participants in the various techniques for rapidly assessing soil quality in the field; and ii) Improve the ability of EATWELL participants in making soil management decisions based on the understanding of soil properties and crop requirements.

3.2. Establish 4–5 field trials on leading grower farms in the Philippines

The field research activities were undertaken on leading grower farms in the Philippines so that opportunities for learning and development and adopting the outcomes from the component were maximised. Key grower groups were engaged to undertake the proposed field research and demonstration activities. This followed approaches and protocols which were successfully used in ACIAR project CP/2005/075 “Integrated Soil and Crop Management for Rehabilitation of Vegetable Production in the Tsunami-affected Areas of NAD Province, Indonesia”.

Five field experiments were set-up in the farmers’ fields at (a) Cabintan, Leyte; (b) Maypayag and Lantapan, Bukidnon; (c) Kapatagan, Davao and (d) Claveria, Misamis Oriental. The same experimental layout was followed in five field trials with varying levels of treatment. It was laid out in the field in a randomized complete block design with four treatments and five replications.

Cabintan is located approximately 18 km northeast of Ormoc City with an elevation of around 900 m above sea level (asl). Common land uses of the area are annual vegetable cropping (e.g. sweet peppers, cabbage, eggplant, tomatoes) and corn production. Other land is left to wild shrubs and forest tree species. The soil in the mountainous area of Cabintan is mainly developed from volcanic tuff, basaltic and andesitic materials which were ejected during the period of active volcanism (Aurelio, 1992 and Asio, 1996). The higher altitude of the area may have affected the agro-climatic pattern of the site, hence intermittent rainfall is always observed throughout the growing season leading to a higher leaching rate of nutrients especially nitrogen.

Bukidnon is considered to be the food basket of Mindanao. High value vegetable crops are most popular for local farmers for domestic consumption supplying as far as the Luzon and Visayas islands. Lettuce, cabbage, tomato, cauliflower, broccoli, squash, potato and sweet potato are just a few among the preferred vegetable crops that are highly suitable in the province. Rainfall in Northern Mindanao is evenly distributed throughout the year. It’s abundant vegetation, natural springs and high elevation contribute to the region’s cool and mild climate. Problems associated with vegetable production in these areas were identified such as soil infertility, soil erodability due to poor structure, inaccessibility to soil testing and inappropriate fertilization. The project site was located in Mapayag, Malaybalay City with an elevation of 1,301 metres asl while Kibangay, Lantapan has an elevation of 1,263 metres asl. These two sites are primarily in agricultural areas most favoured for vegetable cropping.

Kapatagan, Davao City site is located on the southern slopes of Mt. Apo, the Philippines’ highest mountain. Its’ elevation of 1,200 meters asl is highly suitable for temperate vegetable production such as crucifers, potato and carrots. The region has a generally uniform distribution of rainfall throughout the year. Problems associated with these areas are declining fertility status of the soil and diminishing areas of arable land with increasing population growth. Major vegetable products in Mindanao (cabbage, broccoli, eggplant, tomato etc.) are coming from this area, which supplies the nearby regions and even some other parts of the Philippines.

Claveria, Misamis Oriental is located at 980 meters asl. The soil is derived from pyroclastic materials (Mts Mat-i, Balatukan, Sumagaya) are deep and well drained. Claveria soils represent most of the acid uplands in Southeast Asia physically (Mercado, 2007) and socio-economically (Bertumeu, 2005). Tomato farmers in Claveria tend to apply 3-5 times more fertilizers than what are required affecting efficiency and income. Vegetable farmers tend to over-fertilize vegetables in order to secure optimum yield (Morris, 1996) and supply residual nutrients for subsequent crops in the rotation.

VSU, Baybay, Leyte. Three experiments were set up at VSU for nutrient omission trials on cabbage, maize and tomato using soil media to assess the nutrient supplying capacity of soils for vegetables from the 5 different sites (Cabintan, Mapayag, Claveria, Kapatagan and Kibangay) in the southern Philippines.

3.3. Involve farmers at the component inception point to facilitate strong participatory research.

This activity was linked to Activity 3.2 and encouraged farmer participation in the component and maximised the opportunities for training and development, as well as adoption of component outcomes.

3.4. Link with ICRAF/ Landcare and Components 2–5 of HORT 2007/066 to conduct Farmer Field Schools

Collaboration with researchers from ICRAF, Landcare and VSU enabled linkages to be created with existing networks to conduct training workshops and Farmer Techno fora to disseminate component outcomes. See activity 3.4.

Objective 4. Build scientific research capacity of collaborating staff in the Philippines to promote the development of more sustainable and profitable vegetable production in the Philippines (Training and Capacity Building)

4.1. Train component staff in new methods of agricultural and soil research.

The Component provided Philippine collaborators with the opportunity to learn new methods in agricultural and soil research, both within the Philippines and Australia. As part of this, Philippine collaborators were given the responsibility of implementing activities based in the Philippines and writing up and disseminating component outcomes. For example, component team members wrote or co-authored several research and conference papers. It contributed to promoting the development of more sustainable and profitable vegetable production in the Philippines.

4.2. Use the CROA field site as a training resource for visiting collaborating scientists from the Philippines.

One of the strategies for achieving Objective 4 was to use the CROA field site as a training resource for visiting collaborating scientists from the Philippines. This activity was linked to Activity 2.7 and 4.1 and enabled four Philippine collaborating scientists to be trained in field research techniques/ approaches in Australia. The four Philippine scientists visited the NSW DPI vegetable-compost field trial site at CROA, Camden and compost facilities in South Western Sydney in July 2010.

4.3. Selected component team members to visit the CROA field research experiment to learn about Australian R&D and vegetable production systems in Australia.

In conjunction with activities 2.7, 4.1, 4.2 and 4.5, five component team members from the Philippines visited Australia to learn about Australian R&D techniques and Australian vegetable production systems. It was anticipated the skills and experience gained by the Philippines collaborators from visiting Australia would have lasting impacts throughout their careers and have flow on benefits for vegetable growers in the Philippines.

4.4. Selected component team members to attend/ present at relevant national and international conferences.

It was proposed 3–4 component team members would attend and present at national/ international conferences in Australia and Philippines. These were linked to scheduled travel visits by collaborating Australian and Philippine team members to the Philippines and Australia.including the World Congress of Soil Science, Brisbane, August, 2010 (http://www.ccm.com.au/soil/). These would provide an excellent opportunity to show case achievements from the component, contribute to capacity building objectives and establish international linkages.

6 Achievements against activities and outputs/milestones

Objective 1: To define current soil fertility status and management practices

no.	Activity	Planned outputs/ milestones	Completion date	Comments
1.1	Identify soil fertility constraints by: i) interviewing farmers regarding current fertiliser and nutrient management practices; ii) undertaking a baseline survey of soil fertility in key vegetable producing districts and on representative soil types of Mindanao and Leyte. (PC) iii) Conduct nutrient omission pot trials	Documentation of current fertiliser and nutrient management practices Characterisation of soil fertility status in key vegetable producing areas Soil fertility constraints identified	Participatory Assessment – completed February 2009 Soil Survey – completed February 2009 The nutrient omission trials were conducted in late 2010/ early 2011 using 3 key,crops: tomato, cabbage and maize.	Results from these activities were used as the basis for a workshop, which was held at NOMIARC, Malaybalay, Bukidnon in March 2009 to plan and design 5 field experiments. .
1.2	Evaluate alternative nutrient inputs (abundance, nutrient supply, cost, effect on soil physical, chemical and biological properties). (PC)	Quantification and characterisation of alternative nutrient inputs and their potential benefits Identification of organic inputs with the greatest potential for use in vegetable cropping systems	Determination of the characteristics and properties of different chicken dung was completed in November 2009. Investigations into the effects of different input materials on the chemical characteristics of vermi-compost were completed by May 2011.	ICRAF (Jun Mercado) also investigated the role of organic amendments with varying C/N ratios in improving nitrogen use efficiency in tomatoes. Bensive Gabitano (VSU) investigated nitrogen cycling from chicken dung and urea under protected and open cropping as part of his BS student project. A more detailed analysis of the availability and characteristics of alternative inputs in Leyte was undertaken as part of a post-graduate research project (MSc) by Ms Clea Ann Vallejera (VSU).

1.3	*Evaluate treatment/ value adding options (e.g. Composting). (PC)*	*List of viable options for producing stable organic fertilisers and documentation of barriers to adoption*	Evaluation (Sep 2008) Final report (March 2013)	List of options prepared (Vallejera 2011). A vermi-composting facility had been established in Claveria, Mindanao by Dr. Jun Mercado. Other on-farm composting facilities were identified in Cabintan). There is also at least one bio-char facility in Leyte

PC = Partner Country, A = Australia

Objective 2: Develop more productive nutrient management systems for vegetables

no.	Activity	Planned outputs/ milestones	Completion date	Comments
2.1.	Calculate nutrient mass balances for different crop management systems (PC).	Improved understanding of the rates of inputs and removal of critical soil and plant nutrients for vegetable production systems in Leyte and Mindanao	Establishment of mass balance studies as part of field research program (Dec 2008) Final report and publications (March 2013)	Outputs were used to quantify the nutrient application rates required to sustain or increase soil fertility and crop nutrient requirements. i.e. Inform Activities 2.2 and 3.2. The information from the mass balance studies has highlighted the need to match inputs to outputs to ensure long-term soil fertility is maintained
2.2.	Refine how fertiliser inputs are used (rates, timing, crops) (PC).	Establishment of 4-5 field research trials in key vegetable producing areas of Leyte and Mindanao	Establishment of field trials (Dec 2008) Final report and publications (March 2013)	Outputs were used to make recommendations to vegetable growers on how fertiliser inputs should be used in terms of application rates, timing of application, crops to which they are applied. Thus the contributed activities 3.1 and 3.2
2.3.	Using existing research, Identify alternative crop rotation options (e.g. Agro-forestry, tree crops, intercropping) (PC).	Identification of alternative crop rotation options (e.g. Agro-forestry, tree crops, intercropping)	Evaluation of options (Sept 2008) Assessment of different crop rotation options (Dec 2008) Final report and publications (March 2013)	Less emphasis was placed on this strategy. Alternative crop rotation options for managing pests and diseases were evaluated. (e.g. *Brassicaceae* after *Solanaceae* as a biofumigation strategy) in collaboration with HORT/2007/066/3 *Arachis pintoy* has potential for future investigation as a means of fixing for nitrogen in cropping soils.

2.4.	Refine nutrient management strategies for protected cropping systems (PC).	Recommendations on nutrient management strategies for protected cropping systems	Final report and publications (March 2013)	A joint experiment between C1 and C2 was completed at VSU, Baybay. This evaluated the interaction between different rates and sources of N (organic and inorganic) inputs under protected cropping and open field situations (Gabitano *et al.* 2010; Gabitano and Tulin 2010; Tulin *et al.* In Prep a; Tulin *et al.* In Prep c). Experiments on the interaction between different rates of K fertilizers under protected structure and open field conditions were completed as part of student research by 2 High School students (Rabe *et al.* 2010).
2.5.	Undertake Cost Benefit Analysis of different management options and identify constraints to adoption (PC)	The economic cost and benefit of different soil fertility management options will be determined Cost effective management practices identified Constraints to adoption identified	Establishment of field trials (Dec 2008).	The experiments had a strong economics focus Treatments selected were based on the most cost-effective method of supplying the nutrient requirements of the target crop. Likewise options for reducing input costs but achieving the same yield have also been evaluated with varying levels of success. High levels of staff turnover in C5 made continuity of collaboration difficult.

2.6.	Monitor incidence and severity of pests and diseases in response to different treatment option (PC).	Assessments of the effects of soil fertility management options on the incidence and severity of pests and diseases.	Establishment of field trials (Dec 2008)	Diseases have been identified as a limiting factor on several of the field trial sites (e.g. Mapayag, Kapatagan and Cabintan) and have had a confounding/ masking effect on some of the experimental treatments employed.
2.7.	Continue current field research experiment at CROA to evaluate the longer-term benefits of using compost in vegetable production systems (A).	Quantification of the longer term benefits of applying compost in vegetable production systems (CROA field experiment).	Progress reports (Dec 2009 & 2010, 2012)	Built upon 3 years of existing current research at CROA. A 3rd application of compost was applied in late 2011, but the following capsicum crop failed due to weed problems, and record rainfall for a summer period. There were also technical staff absences due to leave which created problems in the 2011/2012 summer.
2.8.	Establish 2-3 demonstration trials in key vegetable growing regions of New South Wales (A).	Demonstration of the benefits of using compost and Component findings disseminated to growers.	Demonstration trials established at NSW DPI Demo Farm UWS, Richmond (May to Dec 2010). Second demonstration trial at NSW DPI Demo Farm, UWS (Dec 2011)	Demo trial 1 showed that 60 dry t/ha compost with ½ urea rate could match the farmer practice for yield. Also demonstrated 1. N drawdown as a problem for compost 2. An apparent suppression of “black rot’ soil-borne disease in cabbages by compost. More than 30 farmers visited the demonstration trial.

PC = Partner Country, A = Australia

Objective 3: Encourage adoption of best management practices

no.	Activity	Planned outputs/ milestones	due date of output/ milestone	Comments
3.1	Develop best management practice guideline and other education and extension material for optimal soil fertility and crop nutrient management in vegetables (PC & A).	Best Management Practice guideline and supporting Technotes/ Primefacts for optimising soil fertility and crop nutrient management in vegetables (	Publication of guideline was planned for March 2012	It was decided not to finalise this guideline because there is still a need for more fundamental information. The framework was used as the basis for the training workshops and subsequent Farmer Techno Fora. Publication of a NSW DPI Primefact for the use of organics in agriculture has been delayed until all results of the field trial are processed.
3.2	Established 4-5 field trials on leading grower farms in the Philippines	Establishment of 4-5 participatory field research trials in the Philippines.	See Activity 1.1	
3.3	Involve farmers in the research early on in the Component and have strong participatory research component.	At least 3-4 farmer groups engaged in Component activities with expected flow on impact to individual members (50-60) and their communities (500-1000).	First participatory activity (1.1) completed in Sep 2008 and on-going thereafter.	Farmers and farmer groups were integrally involved in the field research, extension and training activities of the project.

3.4	Conduct Farmer Field Schools/ Training workshops (Potentially as a joint activity with in collaboration with HORT 2007/066 (2-5)) (PC & A).	6 Farmer Field Schools/ Integrated Crop Management Training workshops in each of the key Vegetable producing areas of Leyte (2), Mindanao (3) and NSW (1)	April 2012	Conducted 17 farmer field days, fora and trainings on Integrated Soil and Crop Nutrient Management in each of the key vegetable producing areas of Leyte (5), Claveria (3), Bukidnon (6) Kapatagan (2) and in NSW The EATWELL training workshop was held at NOMIARC August 2011. Over 24 extension advisors attended. Four farmer Techno Forums were held in Sept/Oct 2011, with over 400 farmers attending. Eight Field Days were conducted in VSU, NOMIARC, and Claveria from 2010-2012.

PC = Partner Country, A = Australia

Objective 4: Build scientific research capacity of collaborating staff in the Philippines to promote the development of more sustainable and profitable vegetable production in the Philippines

no.	Activity	Planned outputs/ milestones	due date of output/ milestone	Comments
4.1	Train component staff in new methods of agricultural and soil research (PC).	Philippine component team members gain experience in managing and implementing multinational Components. Several research and conference papers co-authored by Component team members	On-going during component	17 Reports, 17 conference papers, 5 student dissertations, 1 journal papers and 8-9 more in development.
4.2	Use the CROA field site as a training resource for collaborating scientists from the Philippines. Trip undertaken in July/ August 2010	3-4 PC Collaborating scientists trained in field research techniques/ approaches in Australia.	August 2011	Trip undertaken in July/ August 2010.
4.3	Selected Component team members to visit the CROA field research experiment to learn about Australian R&D and vegetable production systems in Australia.	3-4 Component team members from Philippines to visit Australia to learn about Australian R&D techniques and Australian vegetable production systems.	Trip undertaken in July/ August 2010.	Dr Tulin, Ms Salvani, Dr Mercado and Mr Lapoot visited Australia during in 2010 to attend the World Congress of Soil Science (WCSS) and visit research institution and commercial farms in Victoria, South Australia, NSW and Queensland. Dr Gonzaga visited Australia in 2012 as a John Dillon Fellow and travelled to research institutes including EMAI, Camden and DPI, Gosford. The manager of the VSU soil and plant laboratory, Mrs Godoy visited the NSW DPI laboratory at Wollongbar in April, 2012 for training in new analytical techniques, sample processing and data management.

4.4	Selected Component team members to attend/ present at relevant national and international conferences.	3-4 Component team members to attend/ present at national/ international conferences in Australia and Philippines (linked to scheduled travel visits by collaborating Australian and Philippine team members to the Philippines/ SE Asian region and Australia, respectively.	On-going throughout project	5 papers were published in the proceedings of the World Congress of Soil Science which was held in Brisbane in August 2010. Component 1 team members have had a strong presence at the Philippine Society of Soil Science and Technology Conferences in 2009, 2010 and 2011 to promote and disseminate project outcomes (>9 papers published in proceedings).

PC = Partner Country, A = Australia

7 Key results and discussion

The major Philippines results and discussion are presented in attachment 1 (Tulin and Dorahy 2013).

1.1 Identify soil fertility constraints

Participatory and soil assessment surveys were conducted in five major vegetable producing areas; Kibangay, Bukidnon; Mapayag, Bukidnon; Kapatagan, Davao del Sur; Claveria, Misamis Oriental and Cabintan, Leyte in southern Philippines to define the current nutrient status and management practices involving vegetable production. Five sites were identified in each area representing four regions in Southern Philippines that were identified as vegetable producing farms and represent the major sources of vegetables sold in the Visayas and Mindanao islands. Soil samples were gathered in each site and were analyzed in the laboratory for their physico-chemical characteristics (Attachment 1, page 10) and the nutrient mass balances for vegetable systems were evaluated). Detailed results of the soil characteristics for each of the 5 sites are documented in Appendix 2 (page 46) of Attachment 1. Also see Mercado *et.al.* (2008) which is a report on the Claveria, Misamis Oriental surveys.

In the participatory assessment surveys, more than 100 farmers were interviewed for the current management practices they employed in vegetable production and the major problems they encountered in producing vegetables.

The key outcomes of these investigations were

1) Growers identified lack of capital and high fertilizer prices as a key constraint to vegetable production;

2) However, evaluation of soil fertility and current fertiliser and nutrient management practices suggests growers are undersupplying some nutrients and oversupplying others, leading to nutrient imbalances in the soil.

3) Thus it was an issue of ineffective allocation of limited capital (fertilizer) resources rather than a lack of capital (i.e. point 1) that was a constraint to vegetable production.

These results were used as the basis for a workshop, which was held at NOMIARC, Malaybalay, Bukidnon in March 2009 to plan and design 5 field experiments aimed at overcoming soil fertility constraints

The resulting research program had a strong focus on developing fertiliser strategies, which are based on supplying the most cost-effective method of supplying the nutrient requirements of target vegetable crops.

Grower practices are documented in (Tulin *et al*. 2010 a, b, c).

Soil characterisations are documented in Tulin *et al*. in preparation b).

Soil constraints are documented in Ejoc (2010); Tulin *et al*. (2011) and Tulin *et al.* In Prep a).

Some of the other data collected from the participatory assessment surveys (see Survey form in Attachment 1, page 43) could be valuable as the data should characterise the farmer soil practices in the survey area. Only the conclusions on fertiliser use practices have been reported here.

Nutrient omission pot trials

These were conducted in late 2010/ early 2011 using 3 key crops: tomato, cabbage and maize. They acted as a cheap and simple method for assessing the capacity of soil to supply nutrients to crops and enabled the team to propose preliminary thresholds for soil

N, P and K fertility. However, these trials require validation through additional pot and field trial studies (Figure 1).

The pot trials yielded valuable information on which nutrients are driving the productivity of the systems (N>P>K) and enabled some soil test calibration work to be undertaken. These calibration studies were used to help in interpreting the fertility status of the soils collected in the baseline soil.
The relative yield responses of cabbage, maize and tomato are in figures 4 to 6, Attachment 1.

The results of the nutrient omission trial of cabbage using the soil samples from five various sites indicated that N is the most limiting nutrient followed by P and K (Figure 1).

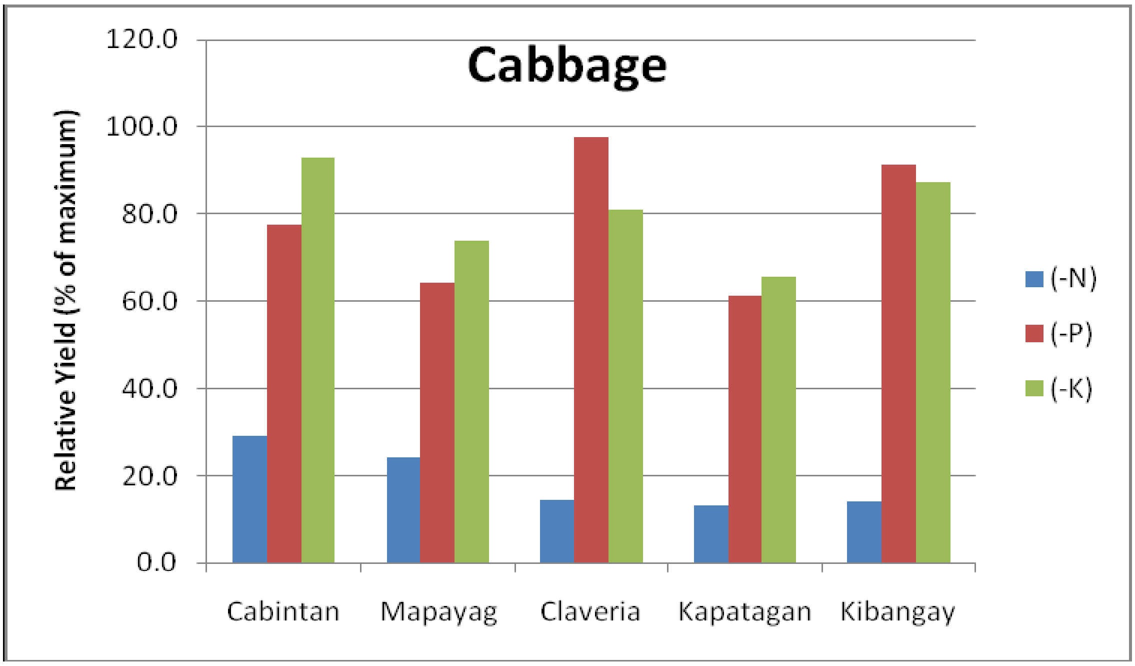

Figure 1. Relative yield of cabbage from five different sites as affected by the absence of one of the primary nutrients needed by the plants.

A framework was also established to guide agricultural researchers through the process of identifying and prioritising key issues surrounding nutrient management in the Southern Philippines and designing a research program with the highest impact and probability of success (Figure 2).

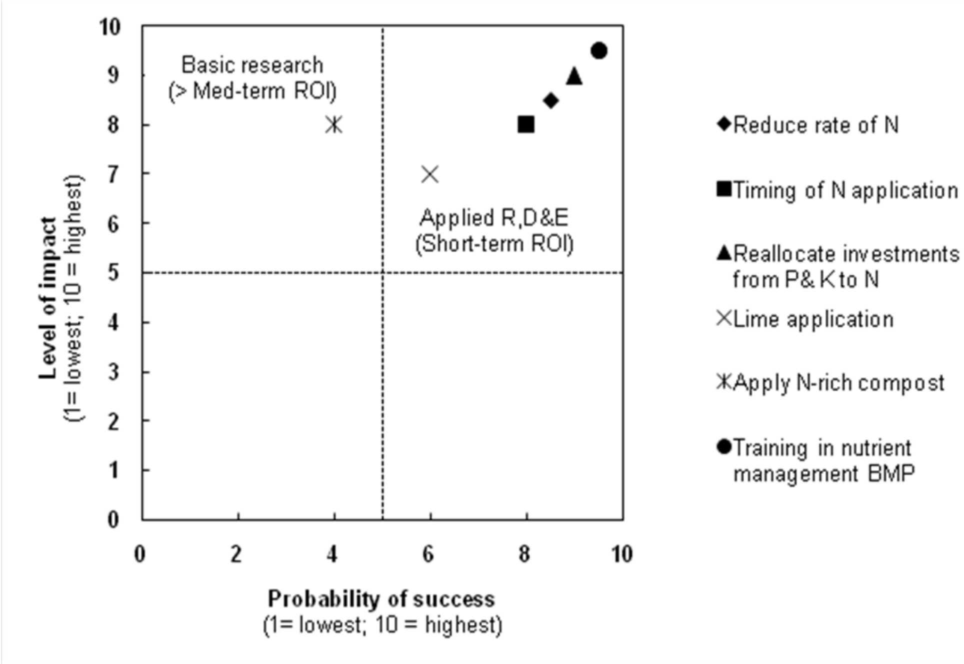

Figure 2. Optimising probability of success and likelihood of impact of research activities through identifying and prioritising issues relating to nutrient management (Dorahy *et al.* 2010).

1.2 Evaluation of alternative nutrient inputs

Quantification and characterisation of alternative nutrient inputs and their potential benefits are documented in Vallejera (2011) and one experimental result is presented in Figure 3 below.

Identification of organic inputs with the greatest potential for use in vegetable cropping systems are documented in Mercado *et al*., in prep a & b (and Table 1) and Sabijon (2010).

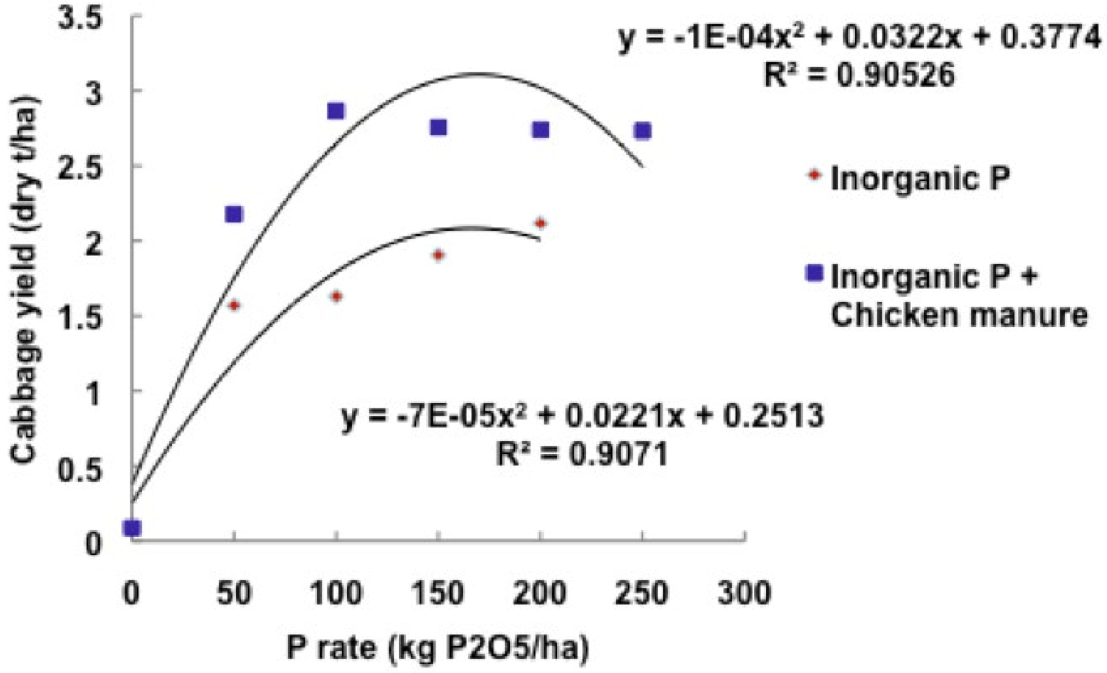

Figure 3. Cabbage yield as a function of inorganic P and with additional chicken manure

Jun Mercado also investigated the role of organic amendments with varying C/N ratios in improving nitrogen use efficiency in tomatoes in Claveria. These included vermicast, chicken manure and corn stubbles that would immobilize N during the vegetable current crop that would reduce N losses and make it more available during the subsequent crops.

Table 1. Quantities of macro and micro-nutrients in 4 commonly used organic amendments in Leyte (Mercado *et al*, In Prep a).

Element	Organic Amendments			
	Swine Manure	Chicken Dung	Mudpress	Vermicast
Macronutrients (%)				
Phosphorus (P)	1.4	2.3	1.6	0.5
Potassium (K)	0.4	5.8	0.5	1.1
Sulfur (S)	0.8	1.1	0.2	0.2
Micronutrients (%)				
Copper (Cu)	340	70	15	10
Zinc (Zn)	470	245	4	25

Bensive Gabitano investigated nitrogen cycling from chicken dung and urea under protected and open cropping as part of his BS student project.

A more detailed analysis of the availability and characteristics of alternative inputs in Leyte was undertaken as part of a post-graduate research project (MSc) by Ms Clea Ann Vallejera (VSU).

The outputs were used to inform which organic inputs are the most appropriate for further evaluation in the field research activities.

Results were presented during the Mindanao wide vermi-forum as well as various farmer training conducted locally and nationally.

1.3 Evaluate treatment / value adding options

A list of viable options for producing stable organic fertilisers and documentation of barriers to adoption was prepared by Vallejera (2011).

A vermi-composting facility had been established in Claveria, Mindanao by Dr. Jun Mercado.

Other on-farm composting facilities were identified in Cabintan.

Several unsuccessful attempts were made to visit a bio-char facility in Leyte

Objective 1 or 1 and 2 summary

Soil testing and understanding of crop nutrient requirements is critical to improving nutrient management in vegetables. In this project, the focus has been on the development of nutrient management programs that will lead to more sustainable, productive and profitable vegetable production systems through the adoption of more judicious and appropriate use of inorganic and organic fertilizer inputs. This was achieved by more effective use of limited fertilizer resources through matching fertilizer inputs to soil and crop nutrient requirements in vegetables, identifying key nutrient productivity drivers and evaluating alternative fertilizer inputs (e.g. vermi-compost)

Organic inputs are often touted as being more sustainable than conventional inorganic fertilisers. However, our results highlight that many of the inputs being used have very low nutrient concentrations, meaning that large quantities of bulky material would be required to supply crop nutrient requirements (Table 1). Moreover, where organic inputs are applied at agronomic rates for one nutrient (eg. nitrogen), significant accumulation of other nutrients (eg. phosphorus) can occur (Figure 5, Tulin and Dorahy 2013). Hence, there are issues with solely relying on organic fertiliser inputs, demonstrating that regardless of source, a balanced approach to nutrient management is required.

2.1 Nutrient mass balances

Mass balances for vegetable production systems were determined as part of the field research program (Table 2). This was based on current nutrient management practices described by farmers and predictions on typical nutrient uptake and removal patterns based on published data for the typical yields described. The studies suggest that nutrients such as N and K were being oversupplied while growers were not applying enough P. This information highlight the need to match inputs to outputs to ensure long-term soil fertility is maintained (Figure 4).

Soil fertility status	+	Nutrient Loading (kg/ha)	-	Nutrient Removal (kg/ha)	=	Nutrient Balance (kg/ha)

Figure 4. Conceptual representation of approach used to determine nutrient balances for vegetable crop production systems evaluated.

Outputs were used to quantify the nutrient application rates required to sustain or increase soil fertility and crop nutrient requirements. ie. inform activities 2.2 and 3.2.

Table 2. Nutrient mass balances for vegetable systems evaluated (from Tulin and Dorahy 2013) page 20).

Region / locality	**Deficit/Surplus (kg/ha)**		
	N	P_2O_5	K_2O
Claveria	154	186	239
Cabintan	140	42	22
Bukidnon	112	120	78
Kapatagan	6	53	-68

For Cabintan, more detailed nutrient deficit or surplus information is provided (Tulin and Dorahy 2013, page 24) for tomato and cabbage.

2.2 Refine how fertilizer used

Five field trials research sites were established in each of the key areas of investigation (Cabintan (Leyte) and Claveria, Kibangay, Lantapan and Kapatagan (Mindanao). Results were variable due to confounding effects of pests, diseases and climatic events. These are documented in Lapoot *et al.* (2010); Mercado *et al.* (2010); Tulin *et al.* (2010a); Tulin *et al.* (2010b).

Alternative rates and forms of nitrogen, phosphorus and potassium were evaluated.

Soil and plant tissue samples from these trials were collected and analysed as part of the mass balance studies. Outputs were used to make recommendations to vegetable growers on how fertiliser inputs should be used in terms of application rates, timing of application, crops to which they are applied. i.e. they contributed background information for activities 3.1 and 3.2.

Table 3. Inferred yield potential of vegetable crops based on soil fertility status (Tulin *et al.*, in Prep b).

Soil fertility status	Nitrogen		Phosphorus		Potassium	
	TN	Yield potential	Bray-1 P	Yield potential	Exch. K	Yield potential
	(%)	(% of max.)	(mg/kg)	(% of max.)	(cmol (+)/kg)	(% of max.)
Low	<0.6	<50	0-10	<75	<0.4	<75
Medium	>0.6	>50	10-20	75-90	0.4-0.6	75-90
High	-	-	>20	>90	>0.6	>90

2.3 Identify alternative crop rotation options.

Comments are provided in section 6, 2.3

2.4 Nutrient management strategies for protected cropping systems

Comments are provided in section 6, 2.4

2.5 Cost benefit analysis of different management options and constraints to adoption

Tools for evaluating the most cost-effective form of the required nutrient were developed. These were used in the EATWELL and Farmer Techno Forums to help farmers and their advisors decide which products will deliver the most agronomically and economically effective form of nutrients.

Further comments are provided in section 6, 2.5

2.6 Monitor incidence and severity of pests and diseases in response to different treatment option

The potential of Wild sunflower (*Tithonia diversifolia*) and brassica residues as a means of controlling bacterial wilt were investigated at Claveria in 2010) as a joint initiative between C1 and C3.

Further comments are provided in section 6, 2.6

Results and discussion for Australian activities 2.7, 2.8, 3.1 and 3.4 which were wholly or totally Australian work are on pages 35 to 38

Objective 3: Encourage adoption of best management practices

A framework was established to guide agricultural researchers in the planning and implementation of high impact researches on integrated nutrient management (Figure 5 and Table 4). Proper allocation of limited resources such as fertilizers will result in the sustainable management of marginal soils. Likewise this approach will lead to better utilization of fertilizers by vegetables, which is valuable in the economic development of our country.

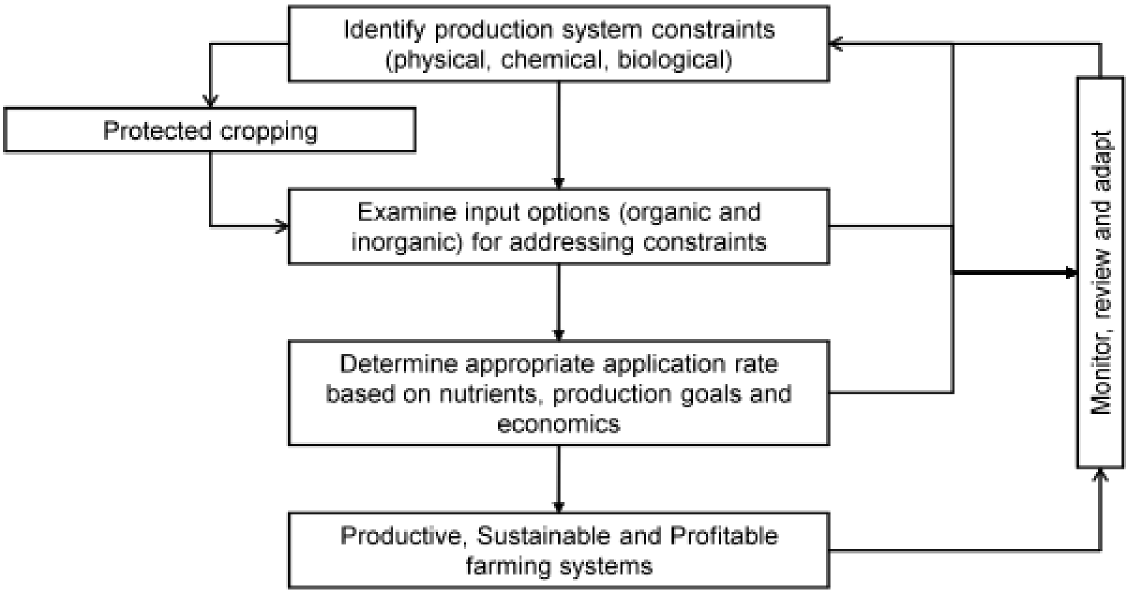

Figure 5. Framework for Integrated Nutrient Management

Table 4. Framework for delivering the key messages and outcomes from the project. These sections are supported by data and output from C1 research activities.

Section 1: What are the key soil fertility issues for vegetable production in the southern Philippines?	What are the key nutrients driving the vegetable production system? How do I identify symptoms of nutrient deficiency? What are the critical limits for available nutrients in these soils? What is the soil fertility status of soils used for vegetable production in the southern Philippines? What is the sustainability of the current systems? Ie are nutrients being applied in excess or less than crop requirements? What are the optimum rates of nutrients for vegetable production systems? Conclusion from this section: This section builds a picture about how to assess soil fertility status and prepare a nutrient budget for a given crop in a range of systems. It also considers the other factors which govern and limit nutrient availability in soils (eg. Leaching, de-nitrification, P sorption etc.) and makesrecommendations about crop nutrient requirements in tropical environments.
Section 2: Organic fertiliser inputs	What is the availability (quantity) and nutrient content of commonly available organic inputs? How much of the N and P in organic fertilisers is available to crops? What is the agronomic effectiveness of organic inputs? Using organic inputs in combination with inorganic fertiliser inputs? What is the effect of organic amendments on soil characteristics? Are there any non-fertiliser benefits from these products? (eg. Improvements in soil structuire, soil OM, disease suppression) Case studies on how to produce organic fertiliser inputs
Section 3: Economics of fertiliser application	How do I determine the most cost-effective source of N,P,K for vegetable production systems?
Section 4: Protected cropping	Are nutrient requirements different under protected cropping systems?
Section 5: Conclusions and recommendations	What are the conclusions and key recommendations for farmers arising from the project? Which of these can be easily adopted and will have a significant impact? Other issues which have masked treatment effects – drought, floods, disease eg. bacterial wilt.
Section 6: References and Further reading	List of outputs and publications from project

Training in nutrient management especially on the application of Best Management Practices is also very important and is reflected in the success of the EATWELL training workshop and Farmer Techno Fora.

3.1 Extension material

It was decided not to proceed with the best bet guidelines within the life of this present project because there is still a need for more fundamental information.

However, the guidelines framework was used as the basis for the EATWELL training workshops and subsequent Farmer Techno Fora.

The Publication of a NSW DPI Primefact for the use of organics in agriculture has been held off until all of the results of the field trial are processed.The results of the CROA compost-vegetable field trial are still being processed and are expected to be important for informing recommendations in a more comprehensive NSW DPI guideline for farmers on the use of recycled organics in agriculture planned for publication in 2013 or 2014.

3.2 Established 4-5 field trials on leading grower farms.

See activity 1.1

3.3 Involve farmers

Farmers and farmer groups were integrally involved in the field research, extension and training activities of the project.

The field trials which were designed using the output from the Participatory and Soil Assessments were conducted in the fields of some of these farmers, who were responsible for managing the trials on a day-to-day basis. Farmers were involved in the conceptualization of all the trials and in managing the crops planted.

3.4 Conduct Farmer Field Schools/ Training workshops

See Section 6, Activity 3.4 and Section 8.4.

The EATWELL workshop and associated Techno Fora were the main mechanisms for delivering the key messages of the project and were highly successful in equipping participants with the tools for working through the various decisions surrounding sustainable soil and nutrient management in vegetable production systems. See report Component 1 Team (2011).

4.1 Train component staff

Philippines team members were responsible for designing and implementing the research program which has been undertaken. New techniques in identifying key research needs and prioritising research activities have been learnt (e.g. Workshop and facilitation techniques). See also section on Capacity Impacts (8.2).

4.2 and 4.3 CROA field site used as a training resource for collaborating scientists from the Philippines and other visits

See section 6, activities 4.2 and 4.3 and section 8.2.

Dr Joe Bacusmo (2012) and Dr Joy Eusebio (2011) also visited the CROA site.

4.4 Attendance at relevant national and international conferences.

See section 6, activities 4.4 and section 8.2.

Summary of results

Some of these notes have been used to develop recommendations (Section 9.2).

Simon Eldridge (NSW DPI) and David Hall (Overall Project Manager, vegetables) conducted a detailed review of the research work in the Philippines in July 2012 (Eldridge and Hall 2012). This review confirmed some valuable information had been collected on;

Chemistry and properties of the vegetable soils of the study areas during the soil characterisation phase,

Nutrient contents of organic amendments used in vegetable production,

Nutrient removal by some important vegetable crops.

Effect of vermicompost on crop growth in pot trials of Dr Mercado (ICRAF). Other suggestions are incorporated in the whole team's discussion notes below.

This review also found that the designs of the NPK nutrient trials were not adequate to determine optimal NPK fertiliser rates for vegetable growing soils of these regions.

Other discussion notes and suggestions

See also recommendations in Section 9.2

Field based nutrient diagnosis (nutrient omission trials based on demonstration design) and refinement of fertiliser forms and rates

Given the challenges associated with farmer access to analytical services (affordability, access, quality assurance, data reliability and turnaround times for making fertiliser decisions) in the Philippines, it would be useful for future projects to undertake some work on field based nutrient diagnosis. Future designs for nutrient trial methodology should be based on 'One Factor at a Time' NPK nutrient trial methodology outlined in Asher *et al.* (2002) and utilized in many successful nutrient field trials (e.g. Maier *et al*. 1989, Chapman *et al*. 1992). Another more complicated design (a reduced factorial) was prepared by NSW DPI (Collins (2011), and this is another option. The more straight forward "one factor at a time" methodology is probably the most likely to provide successful outcomes for future crop nutrient field trial research in the Philippines. Although complex 'reduced factorial designs are also an option for consideration, it is thought that the gains obtained (in terms of a greater understanding of the effect of nutrient interactions on crop yield) from such sophisticated designs do not really make up for the additional complexity that they present for field trial establishment and data analysis at the end of the trial.

This project has made some progress in refining rates and forms of nutrients for vegetable production systems, although further work is required to identify optimal rates and forms of N, P and K for particular situations, using well-designed and controlled field experiments. These would need to be undertaken at university or Department of Agriculture field research stations in the first instance, given the difficulty in accounting for and balancing the forms and rates of nutrient inputs currently used by farmers and managing externalities in farmers' fields.

Soil test calibration studies

The preliminary soil N, P and K threshold concentrations proposed for identifying soils with low, medium and high fertility status from Tulin and Dorahy (2013) [see Attachment 1, Tulin and Dorahy 2013] are the first step in improving soil nutrient management for vegetable production systems in the southern Philippines. However, additional pot and field trial studies are required to validate these recommendations and identify soil tests which are best suited to predicting nutrient supply capacity of soils used for vegetable production systems in the Philippines.

Integration of organic and inorganic inputs

A message arising from the project has been that organic inputs are unlikely to act as substitutes for inorganic fertilisers, and this confirms other studies. However, there are huge opportunities to more effectively integrate organic and inorganic fertilisers to build more resilient and sustainable production systems. Areas that require further investigation include the role of organic amendments in improving nutrient cycling and supply in tropical systems, particularly with respect to improving nitrogen use efficiency through minimizing losses via volatilization and de-nitrification. Likewise further research is required to explore the role of organic amendments in improving soil physical and biological properties

Lab capacity building (Equipment, Personnel, Processes)

One of the challenges of the project has been delays in receiving results of soil and plant analyses, which made it difficult to interpret experimental results and thence make timely decisions about future experimental treatments before the onset of new planting windows. A need has also been identified to implement quality control processes to validate the accuracy of analytical results. The reasons for these challenges have included a lack of human resources, the need to update basic laboratory equipment and more rigorous "chain of command", data management and QA systems. Some of these have been addressed through additional funding from ACIAR for the purchase of new equipment (eg. pH meter, fumehood and water distillation equipment) and the opportunity for Ms Cynthia Godoy to spend time at NSW DPI's Wollongbar laboratories. However, it would be useful for future projects to include or have a discrete component examining these issues (eg. laboratory audits and development of strict protocols and processes) to build laboratory capacity. A draft report on soil testing laboratories, including their capability and QA systems, available for vegetable producers and advisors was prepared after the April 2011 meeting in NOMIARC, but we did not complete this report. At a bigger picture level, it would also be useful to make some comparison of the advantages and disadvantages of donor investment in large centralised laboratories versus smaller regional labs and definition of the roles they should play in providing research and extension services.

Peri-urban Ag in Philippines and Australia - Key drivers Climate Change and Environmental Sustainability

The issue of urban areas acting as nutrient sinks and the subsequent need to manage organic wastes more sustainability is common to Australia and the Philippines. Some of the field sites evaluated in the current project were a long way from urban areas meaning transport of organic wastes (eg. chicken dung, pig manure and vegetable and garden organics) to utilisation areas is difficult. However, there are large numbers of small peri-urban farmers in close proximity to urban areas and so there is an opportunity to work with them and Municipal Authorities to create beneficial reuse and build the resilience of these systems. This could be placed firmly in the context of using organics as carbon inputs to vegetable soils and adapting systems for climate change. The CROA site could continue to act as a valuable resource in such a project and this issue was the primary driver behind its initiation. This could include a more comprehensive survey of types and characteristics of readily available organic inputs.

Irrigation

Most vegetable crops seem to be dryland only. In one cabbage field trial, crops had highly variable yield results and that this was due to a dry period with low rainfall. Apparently there is basically no provision for supplementary irrigation of vegetable crops in Mindanao, with crop water supply being entirely dependent on rainfall. However, there could be some potential benefit in supplying water to vegetables at critical times and to see if this affects final yields.

In contrast, in Australia all vegetable crops are irrigated to ensure that plant available water (PAW) in the soil is such that crop is never water stressed which should ensure maximum yield outcomes are possible.

Provision of some irrigation capacity (e.g. small dams & drip irrigation) might also give Philippine vegetable production systems resilience to address future more variable climate scenarios.

It would be valuable to investigate soil moisture changes over time under these vegetable cropping systems to develop baseline data and assess how much water stress (or suboptimal soil water content) PAW conditions is occurring through the life of a crop in these areas. This could be done with a few sensors and data loggers (e.g. Gbugs etc).

Having the optimal nutrient supply to the crop will maximise yield for rainfed conditions, but optimising water supply and nutrient supply could potentially give a much larger maximum yield potential for a given crop.

In the first instance, a desk top study could look at rainfall patterns and soil water holding capacity and identify whether there is an opportunity to develop a research program around this.

Continuing education, extension and capacity building

Whilst there are many research questions which could be answered, on-going education and extension with respect to basic principles and practices of nutrient and soil management is likely to deliver the greatest benefits to Philippine and Australian farmers for improving the productivity, profitability and sustainability of vegetable systems at the lowest cost. Hence, further refinement and broader delivery of the modules of the EATWELL program used in this component is highly recommended.

Likewise, one of the key achievements of this project has been through building the capacity of the team members and associated staff, particularly with respect to critical thinking, and teaching skills in effectively planning designing, implementing and communicating agricultural research programs. Future projects should also make provision for discrete components which could be used as MS or BS student projects with funding to travel and present research findings at national and international conferences.

All farmer guidelines must be evidence based and use inputs from rigorous analyses of well defined experiments because of the critical importance to farmers of accurate advice.

Results and discussion for Australian activities 2.7, 2.8, 3.1 and 3.4 which were wholly Australian work

Activity 2.7 NSW DPI Compost – vegetable field trial research study, CROA, Camden

The results of the NSW DPI compost-vegetable trial are presented in detail in Appendix 1.

The second phase of the compost vegetable field trial at CROA, demonstrated that;

- A repeat large application of blended green waste compost (62.5 dry t/ha and 125 dry t/ha) can be economical over 10 vegetable crops when capsicum (bell peppers) are the first crop planted after application. Capsicum responded to the repeat compost application by achieving near maximum yield
- The 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 Benefit Cost Ratio of 2.63 and 3.33 respectively, when compared to farmer practices in the Sydney Basin
- The larger application of compost (125 dry t/ha) resulted in significant ($P<0.05$) improvements in soil quality parameters (physical, chemical, biology) compared to the farmer practice soil, immediately after application. These measures included percentage water stable aggregates, carbon %, CEC %, pH, cations, nutrients and soil microbial biomass.
- The extent of difference in the measured values for these soil quality parameters between the compost treatment and 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 the fairly intensive tillage with the rotary hoe. No-tillage or reduced tillage cultivation systems may help to prolong the soil quality benefits of compost application.
- 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 be perhaps reflecting a conditioning of the soil biology from the first application, to respond to further compost inputs. Soil microbial biomass levels for the compost treatment were significantly higher ($P<0.05$) than the farmer practice treatment for crops 6 (capsicum), crop 7 (broccoli), and crop 8 (lettuce).
- Nitrogen availability indexes of 0.10 of Total N for blended greenwaste 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.
- Phosphorus levels in soil also need to be monitored in fields receiving large applications of blended compost. The 2nd application 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. As such, 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.

- Potassium from the full compost treatment (125 dry t/ha) was sufficient to meet requirements of 5 successive vegetable crops in the Sydney environment, although it was evident in the soil test results that a significant amount of the soil exchangeable K was lost from the compost treatment soils by leaching over the length of these 5 crops.

The resultant build up in Available P (Colwell P, Figure 6) in the soil from the second application of compost which had slightly higher P content then 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, to protect the environment.

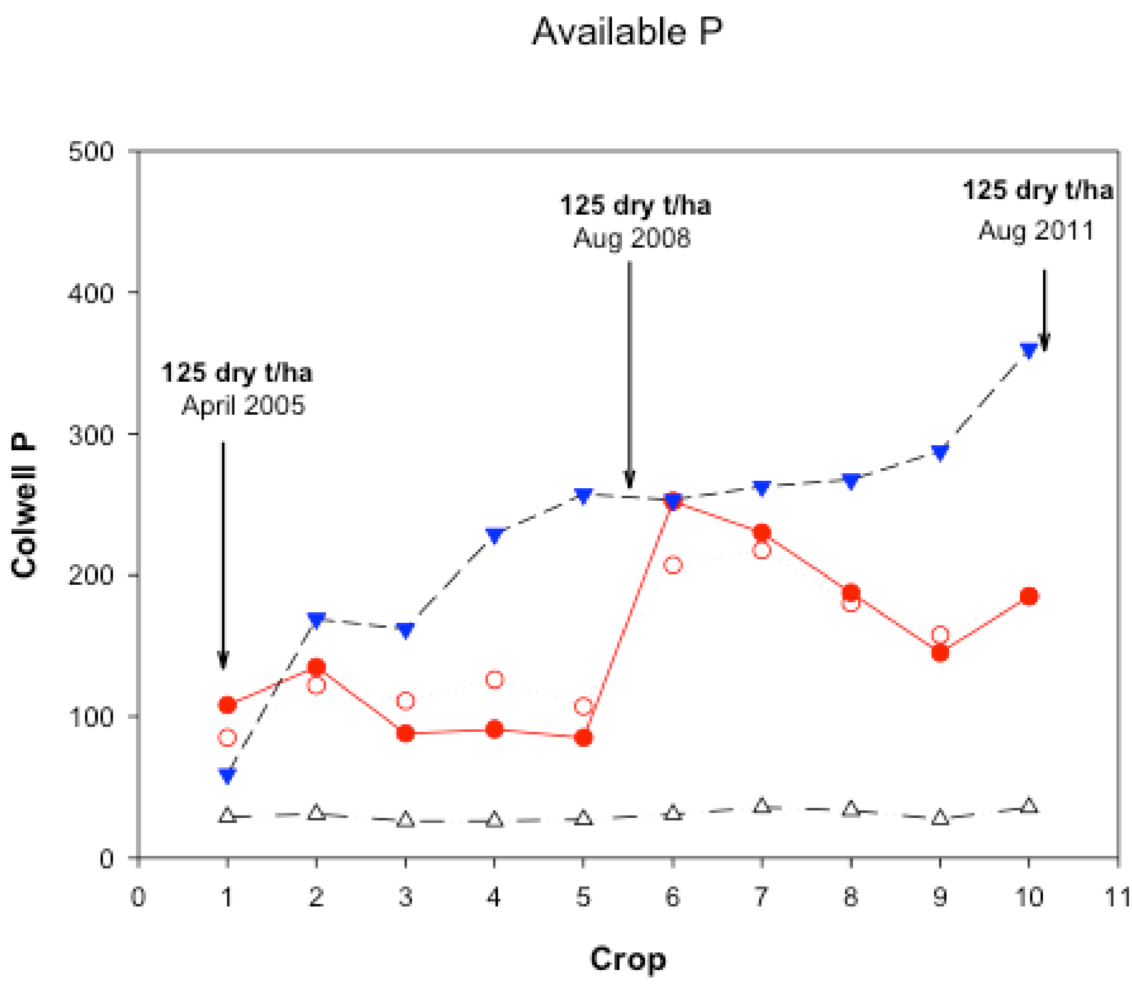

Figure 6. Result of experiments in CROA increasing P levels over time as monitored from 2005 to 2010 (Blue triangles (top line) – poultry litter, red circles (middle lines) - compost, black triangles (bottom lines) - unfertilised control).

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 provided a good maximum application rate for the initial compost applications to a vegetable soil.

Likewise larger applications of compost resulted 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. Thus, applications of inorganic NPK fertiliser can be adjusted accordingly, to ensure that the crop requirements are met in the right quantity at the right time to ensure optimum yield or profit for the farmer and minimum adverse impact on the environment.

A central message from the Australian compost trials is that yield benefits for high value crops such as capsicums and lettuce can make it economically viable to apply large quantities of compost to improve soil health and the environment. A cautionary note is that soil nutrient levels (especially P) need to be monitored and P loadings from organic amendments taken into account with compost applications.

Activity 2.8 Demonstration trials and Activity 3.4 Farmer field days

The demonstration trial 1 showed that 60 dry t/ha compost with ½ urea rate could match farmer practice for yield.

It also demonstrated N drawdown as a problem for compost, especially when it is not incorporated promptly into the soil following spreading.

The trials also demonstrated an apparent suppression of “black rot’ soil-borne disease in cabbages by compost. This disease impacts on late cabbage crops in this area. It was present in the farmer best practice block, but absent from the adjacent compost block. The pathology section of NSW DPI was made aware of a potential capacity of compost to suppress ‘black rot’ disease and this is seen as an opportunity for further research.

About 35 vegetable growers used the trial site for their workshop on soil assessment and irrigation as part of the ‘Nutrient Smart Farms’ project and thus were exposed to the benefits of compost treatment via that course.

Unfortunately the larger field day, which was the aim of this demonstration, was called off due to a failure in another vegetable crop trial which was supposed to be the central focus.

The demonstration trial 2 was unfortunately ruined by record level rainfall which caused localised flooding and severe soil erosion on the site.

The data on soil quality, nutrient supply and carbon levels over time from this project will make a major contribution to NSW DPI extension publications on recycled organic waste in agriculture, which are being planned for the near future

Other discussion notes and research suggestions

See also recommendations Section 9.2

Following on from the Australian CROA compost vegetable trial, it would be valuable for the mixed compost treatment (62.5 dry t compost / ha) and the full compost treatment (125 dry t/ha) to be trialled in the Philippines with capsicum as the first crop. Even though up to 10% of the compost total N can become available, it is recommended that inorganic N as urea be applied at half agronomic rate and crop N status monitored as N drawdown can be a problem, and also since leaching of N is more prominent in the Philippine climate. It would be valuable to evaluate the response from capsicum crops in the Philippines following a repeat application of compost at around the 62.5 dry t/ha rate, to see if similar yield benefits to those recorded in the CROA field trial can be achieved. The 62.5 dry t/ha compost rate treatment should be supplemented with NPK inorganic fertilisers as outlined for this treatment in the CROA study.

The CROA field trial showed that the capsicum crop achieved its maximum potential yield when grown as the first crop following the 2^{nd} application of 125 dry t/ha compost, with the 62.5 dry t/ha rate also achieving a substantial yield increase over farmer practice. But this raises a number of research questions which need to be answered to allow the use of composts to be optimised.

Other research questions are:

1. Does capsicum respond similarly to a first application of compost to soil when it is the first crop? Thus is much of the capsicums' response observed in this field trial relate to the fact that it followed a second application of compost, building on top of the initial large compost application?

2. What rate of compost as a second application is required to achieve maximum yield in capsicum in different soils?

3. Can smaller applications of compost following an initial larger application achieve similar yield responses? Could look at larger applications of compost on small areas to test and evaluate what the benefits are, rather than spreading thinly over whole crop.

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

5. Can similar yield responses to compost be achieved in other important vegetable crops of the Solanaceae family such as tomatoes or potatoes?

6. 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?

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

8 Impacts

8.1 Scientific impacts – now and in 5 years

From the Philippines perspective:

The key impact of the project is that it will provide a framework for managing nutrient inputs and outputs for sustainable nutrient management for vegetable production in the southern Philippines.

The key message for achieving this impact is likely to be as follows:

"Organic inputs are often promoted as the solution to problems of declining soil fertility and agricultural productivity. This is driven by high prices of inorganic fertilisers, opportunities to beneficially reuse recycled organics and a desire to be more "organic". However, recycled organics alone are unlikely to provide the nutrients required to achieve the productivity required to meet the food demands of the Philippines. Nevertheless, they have great potential to be used in conjunction with inorganic fertilisers to increase fertiliser use efficiency, improve soil quality and crop growth.

Sustainable soil fertility and nutrient management entails understanding soil fertility status, matching inputs to outputs and monitoring soil conditions to ensure nutrients do not accumulate or diminish over time".

The continuation of the compost-vegetable field trial in Australia at CROA has provided interesting results in terms of yield response, economics, and changes to soil quality parameters over time, which demonstrates the value of compost and also open up new research questions for refining best practice to optimise the use of compost in mainstream vegetable production. The research team has been invited to write a book chapter on the compost research results and another on carbon sequestration in this system.

8.2 Capacity impacts – now and in 5 years

The most important impact has been in developing the capacity of the Philippines project collaborators on new techniques for evaluating key issues affecting vegetable farmers and designing effective research programs for addressing them. These include new skills in:

- designing and conducting facilitated workshops;
- critically evaluating current nutrient management practices using soil testing and knowledge of crop nutrient requirements; and
- performing economic analysis on the most cost effective forms of available fertilizers for supplying crop nutrient requirements
- scientific writing, with respect to structure, clarity and conciseness.

The project has delivered professional development opportunities for both early stage and mid-career scientists as illustrated below:

In addition to being involved in the project, Dr Anabelle Tulin, Dr Agustin Mercado, Mr Carmelito Lapoot and Ms Juanita Salvani visited Australia in 2010, with highlights of the trip including:

- attending a project meeting in Victoria to monitor, plan and review project activities;
- visiting the NSW DPI's Centre for Recycled Organics in Agriculture (CROA) to learn how field research activities are conducted in Australia;
- touring agricultural enterprises in Victoria, South Australia, New South Wales and Queensland to learn about Australian agricultural production systems and challenges faced by Australian farmers;

- meeting vegetable farmers engaged in large scale commercial vegetable production in Victoria, South Australia and New South Wales and Queensland to learn about their systems and discuss application of new technologies;
- observing the production, harvesting, post- harvest handling and storage and marketing of vegetables to examine opportunities for technology transfer to the Philippines;
- visiting various research laboratories engaged in vegetable research to learn about systems, processes and protocols employed.
- having the opportunity to interact with Australian scientists to discuss research projects and learn about how research is conducted in Australia.
- Visiting large scale commercial composting facilities in Sydney to see how organic waste is managed from municipal areas.
- Attending the World Congress of Soil Science in Brisbane to promote the ACIAR HORT/2007/066/1 project, learn about international research in soil science and develop international networks in the soil science community

Dr Gonzaga visited Australia during February and March 2012 as a John Dillon Fellow and travelled to various research institutes including EMAI, Camden and the DPI at Gosford.

The manager of the VSU soil and plant laboratory, Mrs Cynthia Godoy visited the NSW DPI laboratory at Wollongbar from 21-29 April, 2012 for training in new analytical techniques, sample processing and data management.

Additional funds ($22,000 AUD) have also been secured from ACIAR to purchase new laboratory equipment, namely a Millipore Milli-Q water purification system, spectrophotometer and a fumehood to provide the VSU soils lab with high quality water for analysis, capacity to undertake phosphorus analyses and improvements to OH&S.

Moreover, the project has had a strong focus on building the capacity of the next generation of Philippine Agricultural Scientists through the completion of:

- 1 Master of Science (Soil Science), Clea Vallejera who is now employed as a lecturer at one of VSU's satellite campuses.

- 3 Bachelor of Science final year student projects in 2011, one of whom Jessie Sabijon is employed as a research assistant with Dr Tulin and is keen to undertake post-graduate studies in Soil Science.

- 1 fourth year secondary school project.

- Capacity building of 5 recent graduates through their employment as Research Assistants on the project (Regie Bicamon, Mechelle Ranises, Roland Rallos, Cecille Quinones and Marciana Galambao).

The project has served as an invaluable stepping stone for all of the Research Assistants involved with the project as they have all progressed to further their careers in Soil Science and have left with our full support and encouragement. Regie Bicamon is employed in a soils laboratory with the Department of Agriculture, Butuan City; Mechelle Ranises went to Belgium to undertake a MS in Soil Science; Roland Rallos went to the Philippine Institute for Nuclear Research; Cecille Quinones left to undertake a MS in Germany and Marciana Galambao is keen to undertake a PhD in Soil Health/ Biology in Australia.

Likewise the external capacity building of the project has been through the involvement of more than 5 farmer collaborators, the training of 24 Extension workers at the EATWELL workshops and over 400 farmers who attended the Farmer Techno Forums.

8.3 Community impacts – now and in 5 years

The project has created awareness among farmers in each of the project sites on the importance of developing a site specific nutrient management program based on the efficient utilization of available soil resources. The research program had a strong focus on developing nutrient management strategies, which will lead to more sustainable, productive and profitable vegetable production system through the adoption of more judicious and appropriate use of inorganic and organic fertilizer inputs. Training activities been held with farmer groups and their advisors to assist them in working through the considerations for achieving these goals.

8.3.1 Economic impacts

The NSW DPI compost-vegetable field trial provided data to allow a full financial analysis to be done over 10 vegetable crops, revealing that larger compost applications can potentially more than pay for their cost, if capsicum is planted as the first crop following compost applications.

8.3.2 Social impacts

At this stage, it is difficult to measure social impacts arising from the project. However, the participation of farmers, scientists, researchers and extension workers in the project has encouraged good social interactions and collaboration which will result in positive empowerment of all the partners involved in this project. One very important accomplishment of the project has been the assistance given to two high school students, three undergraduate BSc students and one MSc student at the Visayas State University in meeting the operating costs of their respective research projects. Likewise, five recent graduates were employed as Research Assistants over the life of the project. This not only helped the students financially, but most importantly it gave them exposure to being involved in a multinational collaborative research project. Longer term it is hoped that this will create opportunities for both professional and social advancement, which may not have otherwise been possible.

8.3.3 Environmental impacts

The key environmental impacts will be through the more efficient use of limited resources to ensure soil and water quality is protected. This will be achieved by advocating management practices which will ensure that soil fertility and crop productivity is maintained without leading to depletion or accumulation of nutrients in the soil and potential off-site impacts. The project also strongly advocates the use of organic amendments such as animal manures and vermi-composts in combination with inorganic fertilisers to ensure soil and waste resources are managed in a sustainable manner. This will reduce reliance on inorganic fertilisers, but regardless of the source of nutrients (inorganic or organic), the project has highlighted to need to apply nutrients in a balanced manner.

The work at CROA, showed that large compost applications and regular poultry manure applications, just like inorganic fertilisers, can all eventually lead to a build up of available phosphorus levels in certain soils to a point where they can also pose a threat to water quality and the environment. As such the management of organic fertilisers, just like inorganic fertilisers, must also involve the periodic monitoring of soil nutrient levels, to moderate fertiliser application accordingly. The capacity to apply individual fertiliser elements as N, P or K as inorganic fertiliser, is an important management option for both organic and inorganic fertiliser management to avoid the build up of P especially, as P tends to build up in the soil, whilst K and N are more easily lost through leaching. Provision by Agribusinesses of such fertilisers as Urea for N and Muriate of potash for K, can help provide another option to avoid the excess build up of certain nutrients in the soil, in both Australia and the Philippines.

8.4 Communication and dissemination activities

Seventeen farmer field days, fora and trainings were conducted on Integrated Soil and Crop Nutrient Management Training Workshops in each of the key vegetable producing areas of

Leyte (5)

Claveria (3)

Bukidnon (6)

Kapatagan (2)

and in NSW (1).

Training Workshops

The key communication and extension activities of the project were the EATWELL (Extension Advisor Training Workshop with Excellent Learning Lessons) and Farmer Techno Fora.

The outputs and outcomes of the workshop were that it: i) Equipped EATWELL participants with the information on the physical, chemical and biological aspects of soils; ii) Trained EATWELL participants on nutrient deficiency diagnosis and inculcate in them the importance of using cost-effective fertilizers to attain productivity, sustainability and profitability in farming; iii) Improved and enhanced the capability of EATWELL participants in making soil management decisions based on their understanding on soil properties and crop requirements; iv) Enhanced the capability of the EATWELL participants to disseminate information on the importance of integrated soil and crop nutrient management in vegetable crops in the southern Philippines; and Developed a linkage group between the researchers, extension agents and NGOs. The graduates from the EATWELL workshops then applied the lessons learnt to deliver the subsequent Farmer Techno Fora.

Farmer Techno Forums

- 9th September 2011, NOMIARC, Malaybalay, Bukidnon
- 16th September 2011, MOSCAT, Claveria Misamis Oriental,
- 27th September, 2011Kapatagan, Davao del Sur,
- 4th October, Cabintan Vegetable Farmers Cooperative, Cabintan, Leyte,

The participants in the Farmer Techno Fora took away new skills in: i) Understanding soils; ii) Identifying symptoms of nutrient deficiency; iii) Comparing the costs of different fertilisers; and iii) understanding the importance of individual nutrients.

Over 400 farmers attended.

Component 1 Team. (2011). Extension Advisor training workshop with excellent learning lessons (EATWELL) workshop report. Northern Mindanao Integrated Agricultural Research Center (NOMIARC), Malaybalay, Bukidnon August 22-26, 2011

Internal Workshops

Component 1 Team. 2010/11. ACIAR Project SMCN/2007/066/1 Research review and planning workshops:

- Glenelg Inn, Casterton, Victoria, Australia, July, 2011
- Xavier Estates, Cagayan de Oro, Mindanao, Philippines. 27-29 September, 2010
- Northern Mindanao Integrated Agricultural Research Centre (NOMIARC), Department of Agriculture Regional Field Unit 10 (DA RFU X), Malaybalay, Mindanao, Philippines. 11-15 April, 2011.

Dorahy, C. (Facilitator). (2009). ACIAR Project SCNM/2007/066/1 Scientific writing workshop. NOMIARC, Department of Agricultural Regional Field Unit 10 (DARFU X), Malaybalay, Mindanao, Philippines. 11 November, 2009.

Component 1 Team. (2009). ACIAR Project SCNM/2007/066/1 Research review and planning workshops. NOMIARC, Department of Agricultural Regional Field Unit 10 (DARFU X), Malaybalay, Mindanao, Philippines.9-13 November, 2009 and Visayas State University, Baybay City, Leyte Philippines. 19-23 April, 2009.

Dorahy, C. (2009). ACIAR Project SCNM/2007/066/1 Research methods workshop. NOMIARC, Department of Agricultural Regional Field Unit 10 (DARFU X), Malaybalay, Mindanao, Philippines.16-20 March 2009.

Dorahy, C. (2008). Inception workshop for integrated soil and crop nutrient management in vegetable crops in the southern Philippines. ACIAR Project SCNM/2007/066/1, Marco Polo Hotel, Davao, Philippines, 17-18 July, 2008.

Eldridge, S. M. (Facilitator). (2011). ACIAR Project SMCN/2007/066/1 Workshop on designing nutrient omission demonstration trials. Northern Mindanao Integrated Agricultural Research Centre (NOMIARC), Department of Agriculture Regional Field Unit 10 (DA RFU X), Malaybalay, Mindanao, Philippines. 13 April, 2011.

Publications

The outputs from the project in the Philippines have been substantial with more than 17 reports, 17 conference papers/ posters, 2 journal papers, 5 student dissertations and 13 internal and external workshops. About 8 journal papers are still in development.

In addition, an extensive number of publications targeted at different audiences were produced during the project. These are listed in Section 10.

Posters included (not complete)

Dorahy, C., Tulin, A., Mercado, A. Salvani, J., and Lapoot, C. Prioritising nutrient management research for vegetable production in the southern Philippines.

Mercado, A.R. Material substrates for vermiculture.

Mercado, A.R., and Gonzaga, N.R. Growth and yield performance of tomato in response to NPK omission trial.

Mercado, A.R., Gabitano, B., Arcinal, G., Gonzaga, N., and Dorahy, C. Agronomic response of eggplant on different rates of vermicast, inorganic fertiliser application.

Mercado, A.R., Gabitano, B., Arcinal, G., Gonzaga, N., and Dorahy, C. Agronomic response of tomato on different rates of vermicast, inorganic fertiliser and cover crop application.

Mercado, A.R., Gonzaga, N.R., Torayno, E.J., and Ellacer, R.N. Agronomic performance of tomato in response to application of vermicast using different substrates and rates.

Field Days

Science and technology based farm on chemical-free cabbage and bell pepper production. Northern Mindanao Community Agricultural Rural Research and Development (NOMCARRD), DARFU X, PCARRD, LGU, Imbayao, Malaybalay City, Bukidnon, Philippines. 19 May, 2009.

Field Day showcasing previous results and current research activities. Claveria, Misamis Oriental Philippines. 26 April, 2009.

ACIAR Project SCNM/2007/066/1 Participatory assessments, Isabel, Cabintan (Leyte), Claveria, Kibangay, Lantapan, Kapatagan (Mindanao). September 2008 to February 2009.

Farmers Field Days held in 2009, 2010 and 2011 at Visayas State University wherein the ACIAR Projects were presented to more than 5,000 farmers who attended the yearly events in the university. It is also worth noting that some of the outstanding farmer awardees during the anniversary were all collaborators of the ACIAR Vegetable Project at VSU.

Farmers Field Days held at NOMIARC in 2009, 2010 and 2011 were attended by more than 3,000 farmers each year, who were exposed to the latest developments in vegetable production.

Australian work

In addition to the publication of further papers from the early data from the field trial, there have been two papers accepted for publication in Acta Horticulturae (2013), and a draft paper on the economic analysis from the full 10 crops from this study which is now ready for submission to the Compost Science and Utilization journal (2013). In addition, Simon Eldridge has recently been invited to write a book chapter on his team's compost research in the book 'Bacteria in Agrobiology: biocomposting" edited by DK Marheshwari, for Springer publications.

Additional data on the soil carbon stores for the treatments of the field trial are due back from the laboratory in mid 2013 which will provide the basis of a scientific paper on carbon sequestration in this system.

Final lab results on the soil nutrient levels at the end of crop 10 will provide the basis of a paper summarising the nutrient supply, cycling and fate from these inputs.

The data from the field trial (Activity 2.7) will form the basis of journal publications on (i) economic response; (2) soil quality impacts; (3) soil biology responses, and (4) soil carbon outcomes over the next 12 months.

Presentations

Donovan, N. J., Saleh, F., Chan, K. Y., Eldridge, S. M., Fahey, D., Muirhead, L., Meszaros, I. and Barchia, I. (2011). Use of garden organic compost in a long-term vegetable field trial: Biological Soil Health. *International Symposium – Organic matter management and compost use in horticulture.* University of Adelaide, Adelaide, Australia, April 4 – 7.

Eldridge, S.M., Chan KY, Donovan NJ, Saleh F, Fahey D, Meszaros I, Muirhead L, Barchia, I. (2011) Changes in soil quality over 5 consecutive vegetable crops following the application of garden organics compost. *International Symposium – Organic matter management and compost use in horticulture.* University of Adelaide, Adelaide, Australia, April 4 – 7.

Awards Obtained

The efforts of the project team have been recognised by their peers through numerous awards and scholarships:

1. 2012 John Dillon Fellowship Award for Dr. Nelda R. Gonzaga February 13 to March 21, 2012.
2. 2011 AFMA Research and Development Award for Applied Research during the 23rd NRS Symposium sponsored by DA – BAR.
3. 2011 Best Research Poster Award - 3rd Place during the 23rd Joint RRDEN and VICARP Regional Research and Development/Extension Symposium on August 2-3, 2011.
4. 2011 Regional POSTE Award for Best Research Paper
5. 2011 Best Research Award for Group Life Science Category during the VSULHS Science Fair – First Place (High School Division)

6. 2011 Best Research Poster Award during the VFES Science Fair – First Place (Elementary Division)
7. 2011 Best Research Paper Award during the VFES Science Fair - Second Place (Elementary Division)
8. 2011 Rookie Award for Outstanding Student's Thesis during the ACIAR-PCARRD Annual Meeting last July 2011 for Ms. Clea Anne Vallejera.
9. 2010 PSSST Best Research Award (Junior Researcher Category – Jessie Sabijon and Anabella B. Tulin) given during the 13th PSSST Annual Conference and Scientific Meeting held at Puerto Princesa City, Palawan May 27-28, 2010.
10. 2010 William Dar Research and Development Award for Dr. Anabella B. Tulin given during the PSAI Biennial Conference at BSWM Nov 2010.
11. 2010 VSU Outstanding Researcher Award for Dr. Anabella B. Tulin given during the 86th VSU Anniversary Celebration August 11, 2010.
12. Five posters were presented during the 19th World Congress of Soil Science held in Brisbane Australia last August 1-6, 2010.
13. A poster presenting the results of farm trial in Cabintan was presented as finalist during the Regional Symposium for RDE at VSU August 25-27, 2010.
14. Kibangay trial paper entitled "Enhancing Farmers Knowledge on Soil and Crop Nutrient Management for Vegetable Production in Bukidnon, Mindanao, Philippines" was presented during the NOMIARC In – House Review (June 9, 2010) and during the Regional Agency In – House Review (June 29, 2010), won third place for Best Paper Award (Research Category). It was also presented during the 17th NOMCARRD RHSRD Symposium (August 5-6, 2010).

9 Conclusions and recommendations

9.1 Conclusions

A staged and integrated research program which involved assessment, field research, communication and capacity building activities was developed. The project:

1. Defined current soil fertility status and management practices through: a. benchmarking soil fertility; b. nutrient omission trials to calibrate soil tests and identify the key nutrients which are driving the production system; and c. mass balance studies which assessed the sustainability of current practices.
2. Developed more productive nutrient management systems for vegetables through developing a framework for delivering key messages and encouraging adoption.
3. Promoted adoption of management practices best suited to local conditions through: a. presentation of outcomes from the project at national and international conferences; b. Extension training workshops and farmer techno forums during.
4. Enhanced capacity of local staff to promote and develop more sustainable and profitable vegetable production: a. four Philippine and two Australian collaborators participated in World Congress of Soil Science, Brisbane, 2010; b. two ACIAR funded professional development studies to Australia and c. one MSc and three BSc student projects completed

Soil testing and understanding of crop nutrient requirements was critical to improving nutrient management in vegetables. The focus was on the development of nutrient management programs that would lead to more sustainable, productive and profitable vegetable production systems (Figure 7) through the adoption of more judicious and appropriate use of inorganic and organic fertilizer inputs (Figure 2). This was achieved by more effective use of limited fertilizer resources through matching fertilizer inputs to soil and crop nutrient requirements in vegetables, identifying key nutrient productivity drivers (Figure 1) and evaluating alternative fertilizer inputs (e.g. vermin-compost, Table 1).

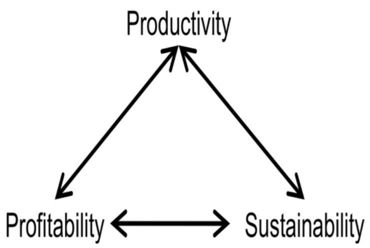

Figure 7. Contribution to economic growth and better livelihoods

The forms and types of alternative nutrient inputs vary from site to site and region to region. A framework was developed (Section 3.1) to guide researchers in their planning and implementation of integrated nutrient management including the use of organic amendments as inputs to vegetable production systems. Proper allocation of limited resources such as fertilizers will result in the sustainable management of marginal soils.

A key message arising from the project is that recycled organics alone are unlikely to provide the nutrients required to achieve desired productivity, but they have great potential to be used in conjunction with inorganic fertilisers to increase fertiliser use efficiency, improve soil quality and crop growth.

The project critically evaluated the current nutrient management practices. Vegetable growers identified lack of capital and high fertilizer prices as key constraints to vegetable production. However, they are undersupplying some nutrients and oversupplying others leading to nutrients imbalances in the soil. The project proposed alternative forms and rates of fertilizer inputs based on the soil test results and the current farmer's practice that should increase the productivity and profitability of vegetable production. A better understanding was gained of the fertility status of the soil which served as the basis for understanding of nutrient application, uptake, removal and mass balances in vegetable production. Thence, the project implemented alternative management practices that are based on the philosophy of matching fertilizer application to the nutrient requirements of the crop and the fertility status of the soil.

9.2 Recommendations

Recommendation 1. That summary data from the farmer survey (Activity 1.1) be published as it should characterise the farmer soil practices in the survey areas. This should assist extension activities and implementation of good soil management practices.

Recommendation 2. That fundamental research work be conducted on determining optimum NPK fertiliser application rates for important vegetable crops on representative sites for the major vegetable growing soil types in the southern Philippines, using either well-designed simple 'one factor at a time' or more complicated 'reduced factorial' NPK field trials.

Recommendation 3: That pot and field trial studies be conducted to validate soil N, P and K threshold concentrations and to identify soil tests which are best suited to predicting nutrient supply capacity of soils used for vegetable production in the Philippines.

Recommendation 4. That work be conducted to integrate organic and inorganic fertilisers to build more resilient and sustainable production systems. Areas include the role of organic amendments in improving nutrient cycling and supply in tropical systems, including improving nitrogen use efficiency through minimizing losses and also exploring the role of organic amendments in improving soil physical and biological properties.

Recommendation 5. That opportunities be examined to improve Philippines laboratory capacity including quality control processes, quality assurance systems, staff resources and leadership, laboratory equipment and data management.

Recommendation 6. It would also be useful to examine advantages and disadvantages of donor investment in large centralised laboratories versus smaller regional laboratories and to define the roles they should play in providing research and extension services.

Recommendation 7. That further investigations be conducted on using organics, including a comprehensive survey of types and characteristics of readily available organic inputs, as carbon inputs to vegetable soils and adapting systems for climate change.

Recommendation 8. That a desk-top study be conducted on rainfall patterns and soil water holding capacity to identify whether there is an opportunity to develop a research program on irrigation of vegetables.

Recommendation 9. That farmer education and training in soil management and crop nutrition be enhanced and that best bet guidelines be evidence based and use inputs from rigorous analyses of well-defined experiments.

Recommendation 10: That the use of large applications (eg. ~100 dry t/ha) of blended garden organic waste compost (eg 20% chicken manure) be promoted as an occasional practice for rejuvinating soil quality in vegetable production soils in Australia, and that this be done in conjunction with responsive crops to ensure an economic return.

Recommendation 11. That further research be carried out on identifying other vegetable crops that exhibit yield responses to compost application, determining optimum rate combinations with inorganic fertilizers, comparing production impacts from composts made from different blends, and the effect of compost in conjunction with different tillage regimes on soil quality and crop production.

Recommendation 12: That a reliable rapid method for determining organic fertiliser equivalency to inorganic NPK fertiliser be developed. This will assist in providing accurate application rates for local organic waste use for use in vegetable production (A, PC).

Recommendation 13: That further opportunities for peri-urban vegetable farmers to use organic wastes as carbon inputs to vegetable soils and as an adaptation to climate change be further examined in both Australia and the Philippines.

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11 Appendixes

11.1 Appendix 1: Detailed report for NSW DPI field trial

Compost-vegetable field trial at CROA, EMAI, Camden 2008 - 2012

BACKGROUND

The ACIAR funding for this project allowed the compost vegetable field trial that was established at CROA, EMAI, Camden in 2005 to be extended for a further 5 crops following a repeat application of compost. The Garden Organics compost (CgO) that was used in this trial was derived from compost produced from source separated garden organics (e.g. grass clippings, prunings, and other vegetation collected from households and municipal areas of Sydney) blended with 10% poultry manure, and composted in accordance with the methods set out in Australian Standard (AS4454-2003). The initial phase (Phase 1) of trial work was conducted under a four year project funded by the NSW Department of Environment and Climate Change and the initial five vegetable crops in Phase 1 were completed in late 2007. This second phase of the compost-vegetable field trial (crop 6 to 10) funded by ACIAR has allowed the impact of compost treatments on soil quality (soil biology, physics, chemistry), crop yield, and crop quality to be studied over a further five crops following the repeat application. It has also allowed an economic analysis to be carried out on the system for the first 5 crops as well as the full 10 crops to compare compost treatments with the standard farmer practice.

MATERIALS AND METHODS

Site and Soil Characteristics

The field trial was located at the NSW Department of Primary Industries 'Centre for Recycled Organics in Agriculture' near Camden (70m Australian Height Datum at 150º 42´32˝E, 34º 05´45.6˝S) in south western Sydney, NSW. The site had a long history of intensive cropping and forage production prior to the field experiment. The soil at the site is a Chromosol/Dermosol inter-grade (Isbell 1996), with a topsoil which is hardsetting with low organic carbon. The site topsoil properties are described in detail in Chan et al., (2008) and Chan *et al*., (2010) and the important properties are presented in Table 6.

Treatments and Experimental Design

The field trial consisted of seven treatments in a randomised complete block design with 4 replicates of each treatment. The treatments were; T1= high P, conventional practice (½ poultry manure and ½ chemical fertiliser); T2= high P, full compost; T3 = high P, compost and chemical fertiliser (½: ½); T4 = low P, conventional (½ poultry manure and ½ chemical fertiliser); T5 = low P, full compost; T6 = low P, compost and chemical fertiliser (½: ½); T7 = control (nil inputs).

Individual plots were 5 m by 6 m with a 1 m buffer between plots. All plots were rotary hoed to a depth of 0.10 m to incorporate added amendments prior to forming the plots areas into three beds, each 1.2 by 6.0 by 0.15 m.

High and low initial levels of soil extractable P was included as a factor in the experiment design because high P levels were found to be typical of vegetable farm soils in the Sydney basin (Chan *et al*. 2007) and as such it was considered important to assess the impact of this on vegetable production (Chan *et al.* 2008). For the high P treatments (T1, T2 and T3), triple superphosphate was applied to each plot at the start of the experiment (2005) at a rate equivalent to 680 kg P/ha and incorporated to 0.10 m, to raise the soil extractable P concentrations to levels similar to those observed in vegetable farm soils (~250 mg/kg in 0.10 m, Chan et al., 2007). The site soil had a low concentration of bicarbonate extractable P (29 mg/kg) and as such ensured the other treatments (T4, T5, T6, T7) were representative of new vegetable farms with no prior history of high fertiliser inputs.

The compost used in this field experiment was a compost derived from source separated garden organics blended with 10% poultry (laying chickens) manure that was composted according to the Australian Standard AS 4454-2003. It was obtained from a commercial supplier and was typical of commercially available compost blends in the Sydney basin. The properties of the composts and poultry manure used in this experiment are presented in Table A1. The compost was applied as a single application at the beginning of the trial in 2005 at a rate of 125 dry t/ha for the full compost treatments (T2, T5) and 62.5 dry t/ha in the mixed compost treatments (T3, T6) and incorporated into the soil to a depth of 15 cm. A repeat of this compost application to these treatment plots was applied in 2008 prior to crop 6. Before the planting of each crop, poultry manure was applied to the conventional practice treatment plots (T1, T4) and triple superphosphate was applied to both the conventional practice treatment (T1, T4) and the mixed compost treatment (T3, T6) plots and both of these amendments were incorporated to a soil depth of 15cm. Potassium as muriate of potash and nitrogen as urea were applied to four treatments (T1, T3, T4, and T6) for each crop as split side dressing surface applications by hand, without incorporation.

Table A1. Properties of soil (T=0), poultry manure and compost used in this investigation

Soil						Exchangeable cations, cmol (+)/ kg			
	pH_{Ca}†	EC‡ dS/m	TOC g/100g	TN g/100g	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 (Crop 1)	5.6	3.14*	21	1.1	19.1	0.38	1200		
Poultry manure (Crops1-10)	8.1	9.20	32	3.1	10.3	2.60	7500		
Compost no.2 (Crop 6)	6.9	5.3	30	1.6	18.8	0.72	2200		

† pH in 1:5 soil/0.01 M $CaCl_2$; ‡electrical conductivity and pHw in 1:5 soil: water extract

; TOC= total organic carbon; TP= total P

The nutrient requirements of each crop were based on industry expert recommendations for agronomic rates of NPK fertiliser (NSW Dept. Primary Industries Agfact / Primefact series (Agfact / Primefact series 2013) and district horticulturalist advice). For the conventional practice treatments (T1 and T4) half of the required nitrogen was applied as the inorganic fertiliser Urea (split surface applications over crop life) and the other half as poultry manure (incorporated into the soil prior to planting). The amount of poultry manure required was calculated from its total nitrogen content assuming an availability index of 0.60 (i.e. 60% of poultry manure total N is available to the crop) from Evanylo and

Sherony., (2002). For the conventional treatment P and K fertiliser rates it was assumed that ½ of the P and K was also supplied by the poultry manure rate determined by total N calculation, and so only half of the recommended agronomic rate of P and K were applied as inorganic fertiliser for this treatment, on this basis.

The full compost rate for treatments T2 and T5 was determined to be 125 dry t/ha based on the recommended agronomic rate for nitrogen for the first crop (broccoli) and the total nitrogen content of the compost, assuming an availability index of 0.10 (Evanylo and Sherony., 2002). The half compost rate for treatments T3 and T6 was thus 62.5 dry t/ha. The compost was applied as one single application at the beginning of the experiment for all compost treatments (i.e. T2 and T5, T3 and T6). The half compost treatments (T3 and T6) received half their NPK for each crop as inorganic fertilisers, identical to that for the conventional treatments (T1 and T4).

For the full compost treatments (T2 and T5), plant sap tests for nitrogen were carried out on the sap from the petioles of each crop to monitor nitrogen nutrition in comparison to conventional practice treatments (T1 and T4). Urea was only applied to the compost treatments when sap test results confirmed crop observation of low nitrate levels. Applications of Urea were not required for the treatments T2 and T5 for the first two crops but were necessary for crops 3 to 5. No potassium or phosphorus fertiliser applications were required for the full compost treatment plots for the 5 vegetable crops. The inorganic chemical and organic fertiliser inputs for each treatment for each of the five crops is summarised in 1 in Orr and Eldridge (2012), See Attachment 2 report.

Crops were managed following recommendations from the NSW Department of Primary Industries (Agfact / Primefact series 2013) and industry handbook (Salvestrin 1998). The crops were drip irrigated with irrigation scheduling based on gypsum blocks (Gbug) soil moisture monitoring of plots. The five vegetable crops in phase 2 of the experiment (i.e. crops 6 to 10) were

6.capsicum (*Capsicum annuum* L.),

7.broccoli (*Brassica oleracea* var. *botrytis* L.),

8. lettuce (*Lactuca sativa Var. capitata* L.),

9.cabbage (*Brassica oleracea* L.), and

10. sweet corn (*Zea mays* L.).

After the harvesting of each crop, all of the non-harvestable crop residues on each plot were incorporated into the soil by rotary hoeing. Further details on the field experiment are provided in Chan et al., (2008) and Chan et al., (2010).

Drip Irrigation was used to supply the crops with water and irrigation decisions were made based on data from soil moisture sensors installed in all the treatment plots in two of the experimental blocks. Irrigation was applied when soil water potential at 20 cm depth was <-30 kPa. Total Irrigation and rainfall for crops 6 to 10 are presented in Table A2.

Soil sampling and preparation

Soil samples were collected following the transplanting of each of the 5 crops (within 1 week of planting) and about 2 days after an irrigation to ensure ideal moisture for subsampling and biological measures. 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, gently broken up into <10 mm fragments and mixed. Subsamples of fresh moist soil for soil biological measurements were passed through a 2mm sieve to remove all stones, macro fauna and roots, and stored at 4ºC until analysed. The rest of the soil sample was air dried at 36ºC until a constant mass was achieved. A subsample of the air dried soil sample was then taken for assessment of soil structural stability. The remaining air dried soil subsamples were then crushed to <2mm and passed through a 2 mm sieve to remove organic crop residues > 2mm, prior to chemical analysis. Soil samples were also taken as per the method described above at the end of some crops for additional soil biological measurements.

Table A2. In-crop rainfall (mm) and irrigation water applied for the five vegetable crops

	6.Capsicum	7.Broccoli	8.Lettuce	9.Cabbage	10.Sweet corn
Season	Oct08-Mar09	June09-Oct09	Feb10-April10	July10-Nov10	Feb11-May11
In-crop rain, mm	230	150	227	322	161
Irrigation, mm	436	117	96	230	430
Irrigation, ML/ha	4.36	1.17	0.96	2.3	4.3

Soil chemical analysis

The air dry <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 apperture 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. This data is presented for crops 6 – Capsicum, Crop 8 – lettuce, and Crop 10 – sweet corn.

Soil biology measurements

The following biological soil parameters (Table A3) were measured:

Table A3. Soil biology measurements.

Biological Indicator	Test	Crops

Biological activity	Basal resipiration	6-7
Microbial activity	Microbial biomass carbon by chloroform fumigation extraction	6-10
Microbial acivity	Hydrolysis of fluorescein diacetate (FDA)	6-10
Microbial diversity & activity	Microbial community analysis using Biolog ECO plate	6-10
Biological diversity	Nematode community analysis	8-9

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 organic 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.

Agronomic measurements

Yield estimates (marketable) were obtained from the harvesting of the centre bed of each plot. Fresh weights were determined for each plot for each crop harvest. Additional market measurements such as number of lettuce per standard market box and number of corn per market box and number of boxes were also done for crops where required for pricing for economic analysis. A subsamples of each fresh crop sample were weighed and dried at 80C to constant mass and weighed again and then ground for subsequent elemental analysis of N,P,K,Ca,Mg, Na, and Cl. Nitrogen was determined by Dumas combustion, Cl calorimetrically after acetic acid extraction, and P as well as cations determined by ICP-AES after acid digestion (USEPA 1996, Kalra 1998).

Penetrometer measurements of soil compaction / hardpan formation

A datalogging 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 in 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 6 and crop 10 in this field experiment.

Statistical Analyses

The data analysis from the field trial accommodated the experimental design where seven treatments were formed as combinations of 2 levels of P status (High and Low P) and 3 levels of P inputs (compost, half compost (or mixed), and conventional farmer practice), and an untreated control, which were randomly allocated within each of four blocks. As such the data were fitted with a linear mixed model as follows;

Response = T vs C + P status + P input + Pstatus:Pinput + ***block*** + ***error***

Where T vs C is the contrast between the treated groups and untreated control, the bold terms were assumed to have random effects and errors assumed to follow a normal distribution. All parameters were estimated using the residual maximum likelihood (REML) technique. Data was analysed using analysis of variance, with least significant difference (LSD) at 5% level being used to test the significances between levels of each factor. A logarithmic transformation of the data was sometimes required, (e.g. Colwell P and nitrate) prior to analysis.

Economic analyses

A financial analysis of the full CROA compost-vegetable field trial results from the 10 vegetable crops grown between 2005 and 2012, and a comparison of benefit cost ratio of the compost and mixed treatments versus the farmer practice was conducted. The methodology and results from this analysis are presented in detail in the report of Orr and Eldridge (2012) which is included in this report as an attachment.

Soil Sampling at end of crop 10.

Following the harvest of the sweet corn at the end of crop 10, the soils in each plot were sampled to a depth of 30 cm to evaluate carbon sequestration and the nutrient stores for the life of the project. For this sampling, 7 soil cores were taken from the three beds in each plot in an identical manner to the standard 0-15 cm samples, except in this case the core tube was pushed down to a depth of 40 cm. The intact soil cores were then pushed out and subsampled at the depths 0-15 cm and 15-30 cm and the 7 cores were composited for each of these depth intervals and each composite sample was weighed. The soil samples were then air dried at 36 C, carefully crumbled and passed through a 2mm sieve removing any coarse plant material > 2mm. These soil samples were fractionated into >53um and <53um according to method of Cambardella and Elliot (1992), to determine particulate organic matter carbon and humus organic matter C respectively, with analysis by Dumas combustion. Inert carbon (black carbon) is currently being determined by hydrogen pyrolysis (hypy) (Ascough et al. 2009) at James Cook University, Cairns. This will give a thorough assessment of the carbon sequestered by this system after 2 compost applications and 10 vegetable crops, as well as the form that the carbon is in. It is the intention, to do further analysis of these samples with Nuclear Magnetic Resonance (NMR) to determine the nature of this stored carbon in the future. These soil samples are also currently being analysed for nutrient levels (NPK and selected micronutrients) to determine a comprehensive nutrient budget for this system over 10 crops, which can be used to inform farmer recommendations and guidelines for compost and poultry manure products.

RESULTS AND DISCUSSION

Crop yield and Quality

The full compost treatment matched or exceeded the yield for farmer practice treatment for all five crops. No significant difference (P<0.05) was found between the crop yields of the compost, mixed, and farmer practice treatments for crops 7 – broccoli, crop 9 – cabbage, and crop 10 – sweet corn (see Table A4).

However for crop 6 – capsicum (Table A5, i.e. the first crop following the repeat application of compost), the full compost treatments achieved yields almost double that of the farmer practice whilst the T6 mixed treatment (1/2 compost: ½ chemical) achieved a yield > 50% higher than the farmer practice yield. To put this in context, the farmer practice mean yields for this crop of 32.8 and 31.9 t/ha are much higher than the average district yield of 12 t/ha (Beckingham and Seymour 1984, NSW Agriculture 1996) and only slightly less than the perceived potential yield of 40 t/ha for capsicums (Bartha 1983). Both the full compost treatments (T2, T5) were well above thi optimum yield level with yields of 62.4 and 59.8 t/ha respectively. The mixed treatment (T6) also achieved a high mean yield with 50.6 t/ha which was significantly higher than the comparable farmer practice treatment, and not significantly different to the full compost yield results. The higher capsicum crop yields in the compost and mixed treatments appears to be due to a significant (P=0.05) increase in the number of marketable fruit produced per plant (see Table 10). The full compost and mixed treatments effectively increased the number of fruit per plant from around 4.6 for farmer practice up to 8.4 and 7.1 respectively, which is almost to the perceived potential limit for the crop of 10 marketable fruit per plant (Bartha 1983). The compost treatments thus helped the capsicum crop to achieve almost optimal production.

The only other crop to achieve a significant yield benefit from the full compost treatment was crop 8 – lettuce, where the full compost treatment (T5) yield of 47 t/ha was 24.7% (P<0.05) higher than the farmer practice treatment (T4) yield of 37.7 t/ha. For this crop. No significant difference was found between the yields of the mixed and farmer practice treatments for this crop.

Results indicate a similar yield between high and low P inputs versions of each treatment for all five crops (i.e. crops 6 – 10), as was the case for crops 1-5.

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 (i.e. Chloride, Calcium, potassium, magnesium, sodium, phosphorus, sulphur, and nitrogen) and this is presented in Tables A6a and A6b. The potassium (K) content of the produce from both the compost and mixed treatments for the first three crops (6-Capsicum, 7-broccoli, and

8-lettuce) was significantly (P<0.05)higher than that in the produce from the farmer practice treatment. This was in the order of 19 tp 46% higher K for the full compost treatments. The differences in K levels were less distinct in the later crops (i.e. 9-cabbage, 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 7 broccoli and crop 8 lettuce. In the broccoli crop the produce of both the compost and the mixed treatments had sodium contents less than half of that of the farmer practice treatments (T4) mean sodium content of 0.56%. For the lettuce crop, the mean sodium content of the compost (T5) and mixed treatments (T6) which was 0.15% and 0.25% respectively compared farvourably with the farmer practice mean sodium content of 0.48%. However no significant differences were found in the cabbage and sweet corn crops which followed these.

Table A4. Yield (fresh weight in t/ha) of the five vegetable crops under the different treatments (different letters within each crop result indicate a significant difference at P=0.05)

Crops	Treatments	P status	Input	Yield (t/ha)
Capsicum	T1	High P	FP	32.8c
	T2	High P	Compost	62.4a
	T3	High P	Mix	45.0bc
	T4	Low P	FP	31.9c
	T5	Low P	compost	59.8a
	T6	Low P	Mix	50.6ab
	T7	Control	nil	4.2d
$LSD_{5\%}$				13.6
Broccoli	T1	High P	FP	17.2a
	T2	High P	Compost	19.0a
	T3	High P	Mix	18.8a
	T4	Low P	FP	19.7a
	T5	Low P	Compost	20.6a
	T6	Low P	Mix	19.4a
	T7	Control	nil	3.8b
$LSD_{5\%}$				4.7
Lettuce	T1	High P	FP	38.3cd
	T2	High P	Compost	45.6ab
	T3	High P	Mix	41.5bcd
	T4	Low P	FP	37.7d
	T5	Low P	Compost	47.0a
	T6	Low P	Mix	41.9bcd
	T7	Control	nil	15.8e
$LSD_{5\%}$				4.8
Cabbage	T1	High P	FP	55.4a
	T2	High P	Compost	57.4a
	T3	High P	Mix	52.9a
	T4	Low P	FP	54.1a
	T5	Low P	Compost	49.4a
	T6	Low P	Mix	58.9a
	T7	Control	nil	28.6b
$LSD_{5\%}$				14.9
Sweet corn	T1	High P	FP	22.2a
	T2	High P	Compost	25.6a
	T3	High P	Mix	22.8a
	T4	Low P	FP	22.7a

	T5	Low P	Compost	24.4a
	T6	Low P	Mix	25.3a
	T7	Control	nil	13. 8b
$LSD_{5\%}$				4.0

Yield (fresh weight in t/ha) of five vegetable crops under different treatments (Least significant difference at *P*=0.05(LSD) value for each crop)

Table A5 Mean Fruit production for crop 6 – capsicum

Treatment	No. fruit / bed (24 plants)	No. fruit / plant	Proportion of optimum no. fruit / plant (%)†
T1 Farmer Practice (FP)-HP	116.0c[1]	4.8	48
T2 – Full compost (Comp) - HP	201.2a	8.4	84
T3 – Mixed (mix) - HP	145.0bc	6.0	60
T4 – Farmer Practice (FP) - LP	111.0c	4.6	46
T5 – Full compost (Comp) - LP	202.5a	8.4	84
T6 – Mixed (mix) - LP	169.8ab	7.1	71
T7 – Nil control - LP	21.2d	0.9	9
LSD (*P*=0.05)	44.03		
Probability (F)	<0.001		

† based on an optimum of 10 fruit per capsicum plant (Bartha 1983).

1 - different letters indicate a significant difference between treatments at *P*=0.05

Benefit cost analysis of composted garden organics in vegetable trials

The cost benefit analysis of the compost vegetable trial for the full 10 crops (Orr and Eldridge 2012, see Appendix 2. for details) revealed that both the full compost treatment and the mixed compost treatments compared favourably to farmer practice on economic grounds. In this scenario, the full compost treatment (125 dry t/ha) and the mix 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 farmers 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.

For the above analysis, the compost (cGO) was valued at $33.8/m^3 (or $67.6/ dry t) for the application prior to crop 1, and $46.5/m^3 (or $93/ dry t) for the application prior to crop 6. This analysis calculated the break even cost of cGO as being $131/m^3 point when comparing the full compost treatment (125 dry t/ha) with farmer practice over these 10 crops [refer to Attachment 2].

Table A6a. Elemental composition (%) of the harvestable parts of each crop

Treatment	Chloride	Ca	K	Mg	Na	P	S	N
Crop 6 - Capsicum								
T1-Farmer practice-HP	0.24b[1]	0.13	3.18c	0.16	0.02	0.42ab	0.26bc	2.73
T2- Compost-HP	0.29b	0.11	3.78ab	0.16	0.02	0.44a	0.27ab	2.85
T3-Mixed-HP	0.29b	0.12	3.58b	0.16	0.02	0.43a	0.26bc	2.75
T4-Farmer Practice-LP	0.23b	0.12	3.10c	0.16	0.02	0.36c	0.25cd	2.78
T5-Compost-LP	0.27b	0.11	3.88a	0.17	0.02	0.42ab	0.28a	2.95
T6-Mixed-LP	0.31b	0.11	3.60ab	0.16	0.02	0.38bc	0.26bc	2.80
T7-Control-LP	0.43a	0.16	2.00d	0.17	0.03	0.26d	0.23d	2.63
Lsd (*P*=0.05)	0.08	NS	0.29	NS	NS	0.05	0.02	NS
Crop 7 - Broccoli								
T1-Farmer practice-HP	0.65	0.56b	3.85b	0.243b	0.43a	0.83ab	0.93bc	4.98bc
T2- Compost-HP	0.68	0.57b	4.55a	0.245b	0.23b	0.82ab	0.94bc	5.03ab
T3-Mixed-HP	0.72	0.57b	4.45a	0.243b	0.32b	0.80b	0.91c	4.78c
T4-Farmer Practice-LP	0.65	0.55b	3.88b	0.250b	0.56a	0.85a	0.94bc	5.38a
T5-Compost-LP	0.71	0.57b	4.85a	0.263a	0.21b	0.83ab	1.03a	5.18ab
T6-Mixed-LP	0.71	0.56b	4.475a	0.248b	0.26b	0.81ab	0.97b	5.08b
T7-Control-LP	0.81	0.69a	3.75b	0.230c	0.22b	0.42c	1.05a	4.15d
Lsd (*P*=0.05)	NS	0.05	0.42	0.010	0.13	0.04	0.05	0.29
Crop 8 - Lettuce								
T1-Farmer practice-HP	1.73bc	0.83d	4.63c	0.33b	0.52b	0.66b	0.24	3.65c
T2- Compost-HP	1.63c	1.01ab	6.75a	0.30c	0.24de	0.67b	0.26	4.10a
T3-Mixed-HP	1.98b	1.10a	6.28ab	0.34b	0.33cd	0.75a	0.28	3.88b
T4-Farmer Practice-LP	1.73bc	0.87cd	4.60c	0.32b	0.48bc	0.67b	0.24	3.63c
T5-Compost-LP	1.50c	0.89cd	6.10ab	0.28c	0.15e	0.66b	0.26	3.85b
T6-Mixed-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

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A6b. Elemental composition (%) of the harvestable parts of each crop (continued)

Treatment	Chloride	Ca	K	Mg	Na	P	S	N
Crop 9 - Cabbage								
T1-Farmer practice-HP	0.57a[1]	0.81	3.93ab	0.30a	0.46	0.68ab	1.07	3.53ab
T2- Compost-HP	0.47bc	0.81	3.45b	0.28ab	0.42	0.63b	1.01	3.35bc
T3-Mixed-HP	0.53ab	0.76	3.48b	0.27ab	0.42	0.63b	0.98	3.28bc
T4-Farmer Practice-LP	0.50abc	0.78	3.45b	0.27ab	0.45	0.64ab	1.00	3.38bc
T5-Compost-LP	0.43c	0.83	3.53a	0.28ab	0.36	0.61b	1.01	3.40bc
T6-Mixed-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-Farmer practice-HP	0.18	0.04b	1.04	0.13ab	<0.01	0.36a	0.11	1.38
T2- Compost-HP	0.17	0.03b	1.04	0.12b	<0.01	0.35ab	0.11	1.38
T3-Mixed-HP	0.16	0.03b	1.02	0.12b	<0.01	0.35ab	0.11	1.45
T4-Farmer Practice-LP	0.17	0.04b	1.03	0.13ab	<0.01	0.34ab	0.11	1.40
T5-Compost-LP	0.16	0.03b	1.01	0.12b	<0.01	0.33bc	0.11	1.48
T6-Mixed-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

1 - different letters indicate a significant difference between treatments at *P*=0.05

Soil Quality

All aspects of soil quality including chemistry /nutrient status, soil structural stability, and the soil biology were monitored over the five crops which followed the repeat compost application prior to crop 6. With all of these parameters, the impacts of the compost applications on soil quality were most pronounced at the time immediately following the incorporation of the compost into the soil (ie. crop 6) and then progressively became less pronounced relative to the farmer practice treatment with time, under this aggressive high tillage regime with the rotary hoe.

(i) Soil structural stability

The results for percentage water stable aggregates in the soil are presented for crop 6 (capsicum), crop 8 (lettuce), and crop 10 (sweet corn) soils at planting in Figure 8. The compost treatment resulted in percentage of water stable soil aggregates in both the >2mm and the >250um size classes which was significantly ($P<0.05$) higher than the farmer practice treatment and this persisted to crop 8, but by crop 10 there was no significant difference in soil aggregate stability between treatments. This is indicative of the role of intensive tillage with rotary hoes in depleting the initial soil structure benefits from the compost 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 farmer practice for crops 6 and 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.

(ii) Soil chemistry,

The soil chemistry soil quality parameters are presented in Table A7 for crop 6, Table A8 for crop 9, and then Table A9 for crop10 (after treatments T1,T3,T4,T6 and T7 had received dolomite applications during liming prior to the sweet corn crop). Immediately following the second large compost application for the compost treatment (i.e. crop 6), the significant ($P<0.05$) improvements to many soil quality parameters including pHca, total organic C, effective cation exchange capacity, and some nutrient levels such as exchangeable K, and total N were obvious. A comparison low soil P status compost (T5) versus farmer practice (T4) treatments shows the benefits of the compost treatment to include a 1pH unit benefit (5.88 vs 4.88), more than double organic C (2.95 vs 1.27), almost double the cation exchange capacity (15.5 vs 8.60), and triple the exchangeable K reserves (2.43 vs 0.76). The only significant negative impacts of the compost treatment were an increase in soil salinity(EC) levels (0.60 vs 0.38) and soil sodicity (4.23% vs 3.13%), but this was confined to the first crop and had no adverse affect on the capsicum crop. However, as such it would be advisable to avoid growing salt sensitive crops for the first crop following compost application. It can also be seen in Table 12 that the mixed treatment (1/2 compost : ½ chemical fertiliser) also significantly ($P<0.05$) improved these soil quality parameters relative to the farmer practice at the start of crop 6, but typically achieving an intermediate improvement somewhere between farmer practice and the full compost treatment.

The compost and farmer practice treatments had comparable mineral N levels and Colwell P levels at the time of crop 6 planting. The high levels of available Colwell P in the compost and mixed treatments suggests that available P levels can build up in the soil with such large applications of compost as well as poultry manure for the farmer practice. This indicates that available P needs to be a limiting factor for the application of composts as it does for other organic wastes such as poultry manure, and that this should be used to determine the limit for compost applications to agricultural lands, based on the environmental risk that it 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).

The soil chemistry results at crop 9 (cabbage) planting show that many of the soil quality benefits from the compost treatment (i.e. pH, TOC, eCEC, and K) were still apparent (i.e. significant difference ($P<0.05$) to farmer practice treatment), but just with the extent of difference between compost and farmer practice treatments, being diminished somewhat with time as a consequence of carbon loss exacerbated by tillage, and also the leaching of nutrients. The soil chemistry results for crop 10 in Table 14, largely re-iterate the findings for crop 9, with the addition of showing the benefits of liming for restoring soil pH and the associated increase in available soil P, for the farmer practice and control treatments.

Figure 8. Percentage water stable soil aggregates for crops 6 – capsicum, 8-lettuce, and 10-sweet corn. (different lower case letters for >2 mm and upper case letters for >250 um aggregate sizes indicate significant difference between treatment means at P=0.05)

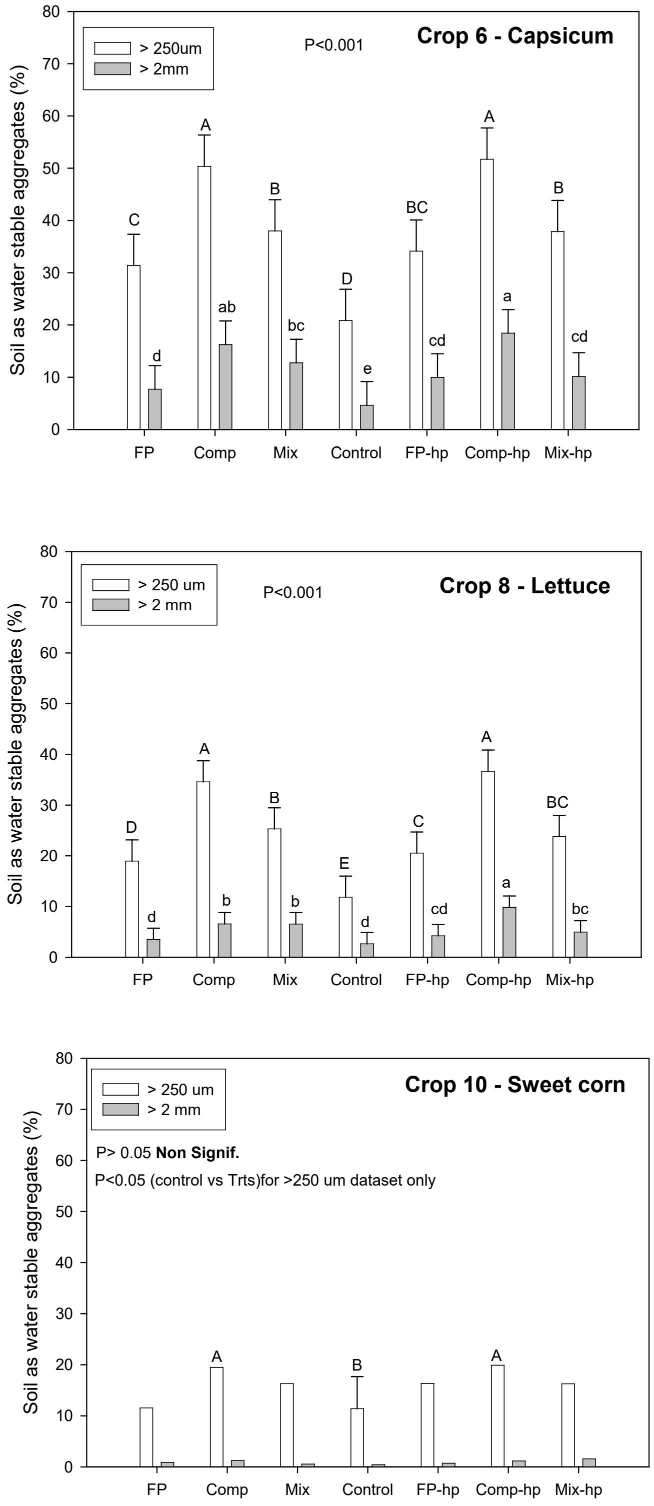

Table A7. Soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 6-Capsicum

Treatment	**EC**	**pHCa**	**TN**	**TOC**	**Exchangeable cations (cmol(+)/kg)**						**exch.Al**	**exch.Na**	**Colwell P**	**NH_4^+-N**	**NO_3^--N**
	(dS/m)	**($CaCl_2$)**	**(g/100 g)**	**(g/100 g)**	**eCEC**	**Al**	**Ca**	**K**	**Mg**	**Na**	**(%)**	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
T1-Farmer Pract - HP	0.35c[1]	4.93c	0.17c	1.38c	9.2c	0.11b	6.45cd	0.79c	1.65b	0.28c	1.23b	3.00c	331 (2.52)a	19.6a	144b
T2- Compost-HP	0.61a	5.85a	0.30a	2.97a	16.0a	0.04c	10.03a	2.33a	2.85a	0.67a	0.18c	4.20a	352 (2.55)a	5.8b	202a
T3-Mixed-HP	0.47b	5.38b	0.23b	2.29b	11.8b	0.06c	7.98b	1.40b	1.95b	0.46b	0.52b	3.88ab	312 (2.49)b	3.9b	175ab
T4-Farmer Pract - LP	0.38c	4.88c	0.17c	1.27c	8.6c	0.10b	6.03d	0.76c	1.45cd	0.27c	1.17b	3.13bc	253 (2.40)c	18.5a	168ab
T5-Compost-LP	0.60a	5.88a	0.31a	2.95a	15.5a	0.04c	9.58a	2.43a	2.78a	0.66a	0.26c	4.23a	252 (2.40)c	5.9b	204a
T6-Mixed-LP	0.49b	5.30b	0.23b	2.26b	11.0b	0.05c	7.18bc	1.38b	1.85b	0.44b	0.46b	4.05ab	207 (2.32)d	5.0b	190a
T7-Control-LP	0.19d	4.88d	0.12d	1.06c	6.9d	0.20a	4.95e	0.32d	1.17d	0.23c	2.98a	3.38bc	31 (1.49)e	1.9b	79c
Lsd (*P*=0.05)	0.08	0.138	0.02	0.34	1.5	0.05	1.09	0.19	0.35	0.08	0.86	0.80	(0.05)	6.0	37

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A8. Soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 9-Cabbage

Treatment	**EC**	**pHCa**	**TN**	**TOC**	**Exchangeable cations (cmol(+)/kg)**						**exch.Al**	**exch.Na**	**Colwell P**	**NH_4^+-N**	**NO_3^--N**
	(dS/m)	**($CaCl_2$)**	**(g/100 g)**	**(g/100 g)**	**eCEC**	**Al**	**Ca**	**K**	**Mg**	**Na**	**(%)**	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
T1-Farmer practice-HP	0.24b[1]	4.93d	0.18bcd	1.35bc	7.80b	0.07ab	5.65cd	0.49cd	1.35b	0.26b	0.96ab	3.35b	299 (2.48)a	20.3b	76b
T2- Compost-HP	0.15e	5.83a	0.21ab	2.13a	10.63a	0.02d	7.98a	0.65ab	1.73a	0.19c	0.15c	1.75de	231 (2.36)a	5.8c	43cd
T3-Mixed-HP	0.15d	5.33b	0.17cd	1.58b	8.35b	0.03cd	6.53b	0.43d	1.19bc	0.18cd	0.39bc	2.13cd	257 (2.41)a	5.4c	46cd
T4-Farmer Practice-LP	0.30a	5.00cd	0.19bc	1.35bc	7.40b	0.06abc	5.18de	0.57bc	1.30b	0.33a	0.81b	4.25a	285 (2.46)a	32.5a	105a
T5-Compost-LP	0.13f	5.95a	0.23a	2.43a	10.15a	0.02d	7.85a	0.68a	1.70a	0.16d	0.17c	1.53e	144 (2.16)b	6.1c	40d
T6-Mixed-LP	0.19c	5.23bc	0.15de	1.48b	8.10b	0.04bc	6.30bc	0.40d	1.18bc	0.18cd	0.43bc	2.28c	169 (2.23)b	6.4c	68bc
T7-Control-LP	0.10g	4.88d	0.13e	0.99c	5.90c	0.09a	4.53e	0.18e	0.95c	0.18cd	1.66a	3.08b	26 (1.42)c	5.3c	33d
Lsd (*P*=0.05)	0.05	0.23	0.04	0.42	0.98	0.04	0.71	0.09	0.27	0.03	0.71	0.41	(0.11)	9.2	26

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A9. Soil chemical properties (0-15 cm) for different treatments at the transplanting of crop 10-Sweet corn

Treatment	EC	pHCa	TN	TOC	Exchangeable cations (cmol(+)/kg)						exch.Al	exch.Na	Colwell P	NH_4^+-N	NO_3^--N
	(dS/m)	($CaCl_2$)	(g/100g)	(g/100 g)	eCEC	Al	Ca	K	Mg	Na	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
T1-Farmer practice-HP	0.63ab	5.38c[1]	0.14b	1.38b	11.25b	0.02ab	7.40b	0.83a	2.45ab	0.50b	0.21ab	4.55a	419 (2.62)a	17.8ab	235ab
T2- Compost-HP	0.59bc	5.58ab	0.18a	2.18a	14.00a	0.01ab	10.20a	0.82a	2.40ab	0.41b	0.02b	2.93cd	297 (2.47)c	7.7bc	230ab
T3-Mixed-HP	0.57bcd	5.48bc	0.15b	1.50b	11.25b	0.01ab	8.50b	0.55b	1.98cd	0.40b	0.08ab	3.43bc	320 (2.51)bc	8.3bc	213b
T4-Farmer Practice-LP	0.71a	5.53abc	0.14b	1.35b	11.25b	0.01ab	7.48b	0.86a	2.60a	0.61a	0.09ab	5.30a	358 (2.55)b	22.3a	270a
T5-Compost-LP	0.47d	5.70a	0.19a	2.15a	13.75a	0.01b	10.03a	0.81a	2.28bc	0.29c	0.02b	2.15d	185 (2.27)d	5.9c	188b
T6-Mixed-LP	0.50cd	5.50bc	0.16b	1.53b	10.75b	0.01ab	7.95b	0.49b	1.83d	0.36bc	0.08ab	3.38bc	185 (2.27)d	5.3c	185b
T7-Control-LP	0.28e	5.58ab	0.10c	0.92c	8.25c	0.02a	5.95c	0.21c	1.75d	0.32c	0.25a	3.83b	35 (1.55)e	4.4c	100c
Lsd (*P*=0.05)	0.11	0.18	0.02	0.30	1.51	0.02	1.15	0.15	0.30	0.08	0.21	0.84	(0.05)	11.4	50

1 - different letters indicate a significant difference between treatments at *P*=0.05

(iii) Soil biology.

This study found that a compost application of 125 dry t/ha significantly enhanced soil biological properties initially, but that this benefit diminished over time as consecutive crops were grown. A repeat application of compost before the sixth crop had a greater influence on soil biological activity than the first application in 2005.

Microbial biomass carbon

The second application of garden organic compost resulted in significantly higher soil microbial biomass carbon levels in the compost treatments compared to the farmers practice treatment for crop 6 (capsicum), crop 7 (broccoli) and crop 8 (lettuce), being up to 100% higher (see Table A10). The differences were not significant for crops 9 (cabbage) and 10 (sweet corn). This contrasts to the microbial biomass C results from the first 5 crops following the first application of compost where no significant differences were found between treatments. This may be indicative of greater benefits to the soil biology resulting from the repeat applications of compost that follow on from the initial compost application, that perhaps primes the soil ecology to be more responsive to subsequent compost inputs.

FDA hydrolase acitivity and soil respiration

FDA hydrolase activity was found to be significantly greater in compost amended soils after crop 6 – capsicum was grown, but there were few significant differences found between treatments in the subsequent crops (see Table A11). The soil respiration rate was only measured for crops 6 capsicum and crop 7 broccoli, but significant differences (*$P<0.05$) in the soil respiration rate* were found between the compost and farmer practice treatments for both of these crops (see Table A12).

Microbial diversity & abundance

Microbial diversity and abundance in the soils as measured by Biolog ECO plate carbon source responses expressed by AWCD (all well colour development) was found to be significantly greater in the compost treatment compared to the farmer practice treatment for crop 6 lettuce. But no significant differences were found between treatments in the soil samples of the following crops (see Table A13)

Nematodes

Nematode populations were only examined in soils from crops 8 (lettuce) and 9 (cabbage). No significant differences ($P<0.05$) were found between soils of the compost and farmer practice treatments, in respect of either the number of plant parasitic nematodes or the number of predatory nematodes for the lettuce crop. However in the cabbage crop, the compost treatment soil was found to have a significantly higher number of predatory nematodes than the farmer practice treatment soil, but no significant differences were found in the numbers of parasitic nematodes in these soils (see Table A14).

Table A10. Soil microbial biomass (0-15 cm) for the different treatments for the five vegetable crops.

Treatment	Mean soil microbial biomass (µg C/g)								
	Capsicum	Capsicum	Broccoli	Lettuce	Lettuce	Cabbage	Cabbage	Corn	Corn
	At planting	At harvest	At planting	At planting	At harvest	At planting	At harvest	At planting	At harvest
T1-Farmer practice-HP	159.3b[1]	85.7cd	165.4b	102.4ab	82.4b	108.3ab	173.0abc	169.5ab	128.6a
T2- Compost-HP	355.9a	290.1a	290.4a	144.4a	157.5a	105.9ab	177.9ab	148.8abc	134.8a
T3-Mixed-HP	202.8b	217.7ab	163b	122.3a	109.0b	103.3ab	141.6bc	108.3bc	131.6a
T4-Farmer Practice-LP	215.8b	117.8cd	144.1b	108.7ab	83.0b	156.6a	162.0abc	97.8c	128.8a
T5-Compost-LP	340.7a	251.9a	243.8a	149.2a	106.5b	139.5a	205.6a	184.2a	150.5a
T6-Mixed-LP	200.5b	154.5bc	152.5b	120.8a	118.0ab	129.4a	162.5abc	137.0abc	112.7a
T7-Control-LP	142.2b	69.3d	79.6c	72.3b	80.5b	62.6b	111.1c	87.3c	122.5a
Lsd (*P*=0.05)	108.8	82.6	63.5	43.5	48.2	53.9	62.9	64.1	44.3

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A11. FDA fluorescence in the soil of the five vegetable crops.

Treatment	Mean FDA fluorescence (µg FDA hydrolysed / g / min)								
	Capsicum	Capsicum	Broccoli	Lettuce	Lettuce	Cabbage	Cabbage	Corn	Corn
	At planting	At harvest	At planting	At planting	At harvest	At planting	At harvest	At planting	At harvest
T1-Farmer practice-HP	0.627 a[1]	0.801 bc	1.039 a	0.886 a	0.789 a	0.877 a	0.752 a	0.877 a	1.356 a
T2- Compost-HP	0.627 a	0.932 ab	1.039 a	0.822 a	0.677 c	0.796 a	0.574 c	0.701 b	1.295 a
T3-Mixed-HP	0.638 a	0.866 ab	1.148 a	0.867 a	0.688 c	0.884 a	0.620 bc	0.679 b	1.378 a
T4-Farmer Practice-LP	0.497 a	0.687 cd	1.057 a	0.861 a	0.785 ab	0.852 a	0.714 ab	0.884 a	1.474 a
T5-Compost-LP	0.692 a	0.979 a	0.972 a	0.881 a	0.704 bc	0.797 a	0.587 c	0.704 b	1.230 a
T6-Mixed-LP	0.574 a	0.831 b	0.951 a	0.812 ab	0.625 c	0.780 a	0.561 c	0.664 b	1.356 a
T7-Control-LP	0.471 a	0.646 d	0.920 a	0.690 b	0.634 c	0.933 a	0.573 c	0.662 b	1.367 a
Lsd (*P*=0.05)	0.165	0.144	0.163	0.132	0.081	0.172	0.127	0.136	0.277

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A12. Soil respiration rate for the capsicum and broccoli crops.

	Mean soil respiration rate (µg CO2-C/g OD soil/h)		
Treatment	**Crop 6 - capsicum**		**Crop 7- broccoli**
	At plant	***At harvest***	***At plant***
T1-Farmer practice-HP	0.44b[1]	0.37cd	0.54cd
T2- Compost-HP	1.41a	0.83a	0.99ab
T3-Mixed-HP	0.50b	0.68ab	0.73bc
T4-Farmer Practice-LP	0.73b	0.43cd	0.63cd
T5-Compost-LP	1.67a	0.77a	1.22a
T6-Mixed-LP	0.68b	0.53bc	0.60cd
T7-Control-LP	0.41b	0.26d	0.39d
Lsd (*P*=0.05)	0.49	0.21	0.32

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A13. Biolog ® All Well Colour Development (AWCD) values for the soils (0-15cm) of crop 8 - lettuce and crop 10 - sweet corn at harvest.

	Mean Biolog AWCD (absorbance at 590nm / 96hr incubation)	
Treatment	**Lettuce**	**Corn**
	At harvest	**At harvest**
T1-Farmer practice-HP	0.02c[1]	0.14bc
T2- Compost-HP	0.41a	0.08c
T3-Mixed-HP	0.09bc	0.19ab
T4-Farmer Practice-LP	0.004c	0.12bc
T5-Compost-LP	0.45a	0.14bc
T6-Mixed-LP	0.11bc	0.09bc
T7-Control-LP	0.22b	0.24a
Lsd (*P*=0.05)	0.17	0.10

1 - different letters indicate a significant difference between treatments at *P*=0.05

Table A14. Mean total plant parasitic nematode and and predatory nematode populations in the soil (0-15cm) at crop harvest for crop 8-lettuce and crop 9- cabbage.

	Total plant parasitic nematodes		**Total predatory nematodes**	
Treatment	**lettuce**	**cabbage**	**lettuce**	**cabbage**
T1-Farmer practice-HP	1.00abc	0.50a[1]	0.23a	0.27bc
T2- Compost-HP	0.42c	0.32a	0.14a	1.04a
T3-Mixed-HP	0.55bc	1.11a	0.49a	0.73abc
T4-Farmer Practice-LP	1.48a	0.54a	0.00a	0.00c
T5-Compost-LP	0.57abc	0.38a	0.27a	0.84ab
T6-Mixed-LP	0.85abc	0.68a	0.00a	0.19bc
T7-Control-LP	1.45ab	0.56a	0.00a	0.00c
Lsd (*P*=0.05)	0.93	0.92	0.53	0.77

1 - different letters indicate a significant difference between treatments at *P*=0.05

CONCLUSIONS

The results of the compost vegetable field experiment at CROA demonstrated that large applications of composted garden organics (cGO) can significantly improve soil quality (soil structure, chemistry, biology), and that these improvements diminish over time with aggressive rotary hoe tillage practices. Soil biology response to the second compost application was more significant and prolonged compared to the responses measured in the initial application of compost at the start of the field trial, indicating perhaps some conditioning or priming of the soil biology from the initial application. The full compost treatment matched or exceeded the yield for farmer practice treatment for all five crops. However it was the response of the capsicum crop planted as the first crop following the application of compost, that was most extraordinary. 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. As such, it is recommended that capsicum be the first crop following compost applications to maximise returns. The soil phosphorus levels in the compost treatment soils showed that soil P can build up to high levels with large compost applications, and that it is important to take soil P levels and compost P levels into account when considering compost applications and determining application rates.

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12 Attachment 1. Report on the Philippine research (Tulin and Dorahy 2013).

This report is available from the authors.
Some of the methodology, results and conclusions are included in the report above
Readers are encouraged to review this report, particularly some of the data in the appendices.

13 Attachment 2. Economics of Compost (Orr and Eldridge 2012)