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Final report

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1 Acknowledgments

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Abbreviations

AAS	Atomic absorption spectrophotometry
ACIAR	Australian Centre for International Agricultural Research
AUD	Australian dollar
AVRDC	Asian Vegetable Research and Development Centre (now World Vegetable Centre)
BSWM	Bureau of Soil and Water Management
CV	Coefficient of variation
DAF	Queensland Department of Agriculture and Fisheries
DAI	Days after inoculation
DM%	Dry matter concentration
EC	Electrical conductivity
FFS	Farmer Field School
FAO	Food and Agriculture Organization
FRSA	Free radical scavenging activity
GPS	Global position system
ICM	Integrated crop management
IRRI	International Rice Research Institute
LFPI	Landcare Foundation of the Philippines (LFPI)

M&E	Monitoring and evaluation
NOT	Nutrient omission trial
ORP	Oxidation-reduction potential
PBAS	Philippine Bureau of Agricultural Statistics,
PCAARRD	Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development
Qld	Queensland (Australia)
ROI	Return on investment
SOM	Soil organic matter
STAR	Statistical Tool for Agricultural Research ()
TDS	Total dissolved solids
TYLCV	Tomato yellow leaf curl virus
UPLB	University of the Philippines Los Baños (UPLB),
USDA	United States Department of Agriculture
UQ	University of Queensland
USTP	University of Science and Technology of Southern Philippines
VSU	Visayas State University
WHC	Water holding capacity

2 Executive summary

In the southern Philippines the security of vegetable production and high vegetable cost are critical issues. This greatly contributes to the low rate of vegetable consumption, particularly in the poorer regions of Samar, Mindanao, Leyte, and Bohol. Due to favourable soil and climatic conditions, the upland acidic soils are widely cultivated to vegetables, but high rainfall (2.0 m to 4.0 m/year) and steep slopes present a major challenge in maintaining soil fertility and mitigating negative environmental impacts. Considerable vegetable production is also practiced on alkaline calcareous soils, hence there is a diverse range of soils and climates under which vegetables are grown giving a wide range of potential soil and crop nutrition constraints. Only limited research has been conducted to identify the key soil constraints in Philippine vegetable production systems. In the Philippines a diverse range of vegetable cropping systems is practiced broadly including open field, protected, and organic production. Protected cropping systems have been developed in response to the adverse climatic impacts of typhoons, and organic production has been promoted by the national government. A further complexity to this is the large range of vegetable crops grown across the regions. The management of soil and crop nutritional constraints across the diversity of vegetable production systems is a critical research and development issue.

Project SMCN/2012/029 was developed to address soil and nutritional constraints to vegetable production in the Southern Philippines and particularly the priority areas of Leyte, Northern Mindanao, and Bohol.

To achieve this the project had five key objectives including:-

Objective 1: To determine the key soil constraints that impact on vegetable production.

Objective 2: To compare production, soil fertility and economics of vegetable production from organic, conventional, and protected systems.

Objective 3: To develop improved and targeted site-specific nutrient management strategies.

Objective 4: Assess the interaction between vegetable genetics and soil and nutrient limitations.

Objective 5: To deliver training and extension to advance soil and nutrient management skills in extension and research staff.

Under the first objective, soil and plant surveys were conducted in Leyte, Claveria, Bukidnon, Bohol, Samar, and Davao. A total of about 160 vegetable farms were surveyed and farmers were interviewed to collect data on crop management practices. The survey was conducted across a range of soil types used for vegetable production from strongly acidic (pH 4.5) to highly alkaline (pH 8.2). Not surprisingly, a range of nutrient disorders are expressed. Across acidic upland soils there was considerable variability in pH, due to varying combinations of inherent acidity and farmer liming practices. In the Cabintan area of Leyte and Claveria in Mindanao, acidity is a major constraint and a large number of the soil samples (60-70%) had pH values less than 5.5. Overall the soil and plant survey and farmer practices survey confirmed excessive application of nitrogen (N), phosphorus (P), and potassium (K) are key issues, though site specific variability was identified. For example, in the same region some farms showed deficiencies of P and K whilst others had high P and K status. Survey and nutrient response data highlighted nutrient limitations to zinc (Zn), calcium (Ca), magnesium (Mg), and manganese (Mn) were identified. Despite the generally excessive fertiliser application, surveyed farmers nonetheless identified poor soil fertility as a key soil constraint and the basis for their application of high rates of a wide array chemical and organic fertilisers.

A survey of reference leaves from cabbage crops of Cabintan (Leyte), and of Claveria and Bukidnon (Northern Mindanao). In general, the average tissue concentrations for all elements were higher from Cabintan and Claveria compared with Bukidnon. Consistent with the other survey data, levels of all major elements (N, P, K, Ca, Mg, and S) were adequate to high. However, concentrations of Cu, Zn, and Mn tended to be variable but overall the mean concentrations were very high. The high concentrations of Cu and Zn is likely due to application of chicken manure, at rates that gave Cu and Zn applications that are about 3 times crop demand, and also with the application of Zn and Cu crop protectant chemicals. The problem of excessive Mn was observed on acidic upland soils that are inherently high in available Mn, though Mn crop protectant fungicides are also widely used. Nutrient omission trials were conducted on a range of soils (including calcareous and acidic soils) to evaluate nutrient limitations on vegetable growth. On the acidic soils, these trials highlighted deficiencies of all major elements (N, P, K, Ca, Mg, and S) and variability in the expression of micronutrient deficiencies. However, responses to most micronutrients were nonetheless observed. In the alkaline soils, responses to major and micronutrients were observed. An outcome of this activity is that the likely crop limitations are now well understood and sites can be selected where a range of practice changes/treatments can be implemented to address soil and nutrient limitations. Crop growth limitations due to micronutrients are not generally addressed by Philippine farmers except inadvertently through chicken manure application. The application of chicken manure at typical rates used by Philippine vegetable farmers gives strongly unbalanced nutrient application in relation to crop demand.

The project has also completed a large series of fertiliser response experiments over a range of crops (tomato, sweet pepper, cabbage, eggplant, and lettuce) in the wet and dry seasons. This research has been conducted over a range of cultivars for each crop species and identifies clear differences in nutrient response profiles. The research has shown a synergistic effect in the addition of chicken manure and the optimised N application rate. For sweet pepper and eggplant the optimal rates for chicken manure are 7.5 t ha^{-1}, N about 150 kg N ha^{-1}, and P at about 65 kg P ha^{-1}. Though the mechanism for this synergy is not yet understood, it is likely to relate to the micronutrient content of the chicken manure combined with the optimised N rate. Assessments of food quality traits in relation to crop nutrient management strategies shows that key food quality traits (ascorbic acid and free radical scavenging) are greatest under the optimised nutrient management regimen.

Further field experimentation has compared the productivity of tomato and sweet pepper under a range of combinations of organic and conventional practices (including factorial combinations of crop nutrition and pesticide). The experiments have demonstrated that organic based systems (ie. those that rely solely on organic nutrient input) do not achieve yields comparable to those achieved in conventional based systems where mineral or mineral plus organic nutrient sources are used. Furthermore, a standard application of chicken manure (~10 t ha^{-1}) applies 20 times the whole crop demand for P and 8 times that for Cu highlighting potential environmental issues. These issues, combined with the limited availability of chicken manure, should be considered in programs that promote farmer adoption of organic production. With the implementation of policies and programs that promote wide-scale adoption of organic production practices effective management of crop nutrition to deliver high yield represents a major challenge.

Australian research on capsicum root system improvement identifies several elite lines of *Capsicum chinense* that confer improved capsicum productivity when used as grafting rootstocks, however the exact mechanisms (soil limitations to productivity) are not understood and require further investigation.

Experimentation using a biostimulant product (MykoPlus), has shown that, when used with low application rates of P, cabbage crop yield is increased substantially (about 40-50%) compared with equivalent treatments where it is not used. The mechanism that underpins this improvement is also not yet understood since the product is a complex mixture of mycorrhizal fungi, nitrogen fixing bacteria, phosphorus solubilisers and growth hormone secretors.

Solution culture studies have assessed the interaction between pH, Al and pathogen incidence. This shows a direct relationship between infection with Pythium and solution pH but in the presence of toxic Al Pythium effects are less severe perhaps indicating high Al concentrations could affect the Pythium. Importantly, this research has shown a link between soil acidity constraints and expression of soil borne pathogens; a major issue for intensive vegetable production.

Best management demonstration trials were completed on collaborators properties in the priority areas. In the Claveria trial, the improved nutrient practice gave a cabbage yield of 24.7 tonne ha^{-1} compared with the farmer practice of 15.6 tonne ha^{-1}. During the last year of the project training was delivered to almost 300 farmers in the southern Philippines and a further 200 farmers attended field days.

A highlight of the project capacity building was a visit to Australia by 10 members of the Philippine project team representing four of the collaborating groups from 17 to 30 April 2016. The visit provided a broad training opportunity that included specialised laboratory based studies and demonstrations, field experimental sites, commercial farming operations, and landscape production issues. The latter having a particular focus on the ‘old’ Australian soils and landscape that contrast with the young Philippine landscape. The solution culture bioassay technique for assessing Al toxicity effects on vegetables was implemented from this trip by UPLB and is now being effectively used to evaluate impacts of soil acidity (pH and Al) and other soil constraints on vegetable root system growth.

3 Background

The security of food production and high food cost are critical issues in the Southern Philippines, especially in the poorer provinces and regions of Samar, Mindanao, Leyte, and Bohol. Across the Philippines, of the 94 million people, more than 42 million live on less than $2 AUD a day (AusAID 2012). The cost of vegetables is relatively high, with the price of the most common vegetables (potato, tomato, eggplant, sweet pepper, squash, and cabbage) ranging from about $0.50 to $1.00 (AUD) per kg (Philippine Statistics Authority). The low productivity and high cost of vegetables are the main factors contributing to the low rate of consumption (Table 3.1).

Table 3.1. Production data for key vegetable crops grown in the Philippines 2010.

Crop	Area (ha)	Yield (t ha^{-1})	Farm price (USD kg^{-1})
Cabbages	8,561	15.1	$0.18
Cauliflowers and broccoli	987	11.2	$0.38
Peppers	5,114	4.1	$0.48
Eggplants	21,426	9.7	$0.27
Lettuce	451	7.9	$0.41
Potatoes	8,129	15.3	$0.56
Pumpkins, squash, gourds	21,270	16.1	$0.18
Sweet potatoes	110,148	4.9	$0.22
Tomatoes	17,663	11.6	$0.27

Philippine Statistics Authority formerly Philippine Bureau of Agricultural Statistics 2013

In the Philippines the high rainfall (2.0 m to 4.0 m/year) on steeply sloping cultivated landscapes presents a major challenge in maintaining soil fertility. Though soil fertility greatly limits Philippine vegetable farming productivity, only limited research has been conducted to identify the key soil constraints. However, based on research on grains and pulses, a broad complex of problems including low base nutrient fertility, acid-soil infertility, low organic carbon, and specific micronutrient limitations are likely to be the limiting factors.

In the previous ACIAR SMCN project evidence was presented to show that soil acidity is a likely limitation on vegetable production in the Philippines (Tulin et al. 2010). In Cabintan, Leyte soil pH varied between 4.55 to 5.01 (Tulin et al. 2010) and at this pH soil solution concentrations of plant-toxic monomeric aluminium (Al) are likely to greatly reduce crop yields. Severe Al toxicity was observed in maize in Claveria (Harper 2013), however, worldwide there is a dearth of information on good diagnostics to quantify the effects of soil acidity on vegetable production. This lack of knowledge is important because different amelioration strategies may need to be adopted to address the specific constraints to plant growth at a particular site; liming will raise soil pH, but may not result in improved crop performance if other constraints limit plant growth. Thus this project has identified a need to develop a more fundamental understanding of the key constraints to Philippine vegetable production, in this way permitting the development of effective solutions to soil productivity issues.

At the scoping study stage, the Philippines National Government had implemented a policy aimed at fully shifting agriculture towards organic production ("Organic Agriculture Act of 2010") which was reflected in targets for organic production under PCAARRDs strategic plan (2012). Increasing the productivity of vegetable cropping (both organic and conventional) to achieve target yields was a key PCAARRD priority (Table 3.2). The focus on organic production is to transition agriculture to strict registered organic systems. In the absence of mineral fertiliser application, achieving high yielding organic vegetable production was considered a major challenge. This project aimed to develop objective data that would compare the productivity and economics of organic, conventional, and protected production.

Table 3.2. Current and target yields for key vegetable crops set by PCAARRD.

Crop	**Yield (t ha^{-1})**			
	Current	**PCAARRD Conv. 2016 target**	**PCAARRD Organic 2016 target**	**Typical Australian Yield***
Cabbages	15.1	19.81	20.9	≈120-160
Peppers	4.1	13.9	12.1	≈40-50
Eggplants	9.7	13.9	12.1	na
Pumpkins, squash, gourds	16.1	17.3	19.8	≈40
Tomatoes	11.6	13.9	12.1	≈150
*From survey data Harper (unpublished) na denotes not available				

Fertiliser represents a major production cost to vegetable farmers in the Philippines representing about 37% of total costs (PBAS 2013). At the development of the project, a key Philippine Government priority was to develop cost effective technologies for fertiliser management in conventional and organic production. In organic vegetable production, crop nutrient deficits and unbalanced nutrient application were considered likely key limitations, whilst in conventional systems the overuse of mineral N fertiliser was a major issue (Harper 2013). Despite this, there was no specific crop nutrient response information available for vegetable production, and the development of this would substantially increase yield whilst reducing costs. The need for accurate fertiliser response data was supported by the key project partners and farmers.

In Australia, the development of pepper germplasm with high nutrient use efficiency traits was important in addressing Australian and Queensland Government priorities for improved environmental outcomes for the Great Barrier Reef. The research aimed to identify the sensitivity of capsicum germplasm to nutrient uptake and key soil acidity limitations (eg. Al toxicity) with the aim to improve genetic adaption to acidic soils. At the development stage, PCAARRD had identified that improved varieties for conventional and organic vegetable production was also a key issue in the development of high productivity systems in the Philippines.

The effects of micronutrient limitations on vegetable crop productivity on acidic and alkaline (calcareous) soils were not well defined in the Philippines. Once identified, these limitations are easily and cheaply corrected, whilst delivering substantial improvements in vegetable crop yield and quality. Thus, development of the capacity to identify micronutrient limitations was an important aspect of the project.

A broad ranging research strategy was implemented to improve vegetable soil and nutrient management. The approach adopted aimed at matching the specific needs of each of the key identified vegetable production areas in the Southern Philippines. A critical part of the strategy was that the project was one of four ACIAR projects that collectively addressed vegetable production and marketing limitations in the Philippines, including postharvest, integrated crop management, and supply chain management providing a whole system focus.

The strategy in this proposal was to initially identify the key soil and nutrient constraints to vegetable production then to develop a more detailed understanding of the nutrient limitation through soil and crop plant nutrient surveying (to provide information on the current situation), and through the use of nutrient budgeting (to indicate the trajectory of the cropping system). This component of the strategy was developed with the partners in recognition of the need to understand key limitations such that appropriate interventions could be developed to improve productivity. The information developed was to include data on major nutrient issues, micronutrient limitations, and potential for soil acidity impacts on vegetable production, hence covering the broad scope of nutritional and soil fertility issues that impact on acidic soil management. Subsequently, this comprehensive and representative suite of data could be used in conjunction with existing soil maps to better understand the relationships between soil type, cropping system, and nutrient limitations. In this way detailed data, collected for a limited number of sites, could be used to identify potential limitations in other situations, allowing a broad application across Philippine regions other than just the focal sites.

A program consisting of a series of research and demonstration trials was developed with collaborators that aimed to develop specific nutrient response profiles for the key vegetables. To complement this, the research strategy identified the need to evaluate the sensitivity of key vegetable crops to soil acidity constraints. Worldwide the effect of soil acidity on vegetable crop production has not received much attention particularly in tropical developing countries. The intensification of vegetable farming systems requires a more prescriptive approach to addressing soil and nutrient constraints. The project assembled a collaborative team from Australia (Qld Department of Agriculture and Fisheries (DAF) and The University of Queensland (UQ)) along with the Philippine team of Visayas State University (VSU), Bureau of Soil and Water Management (BSWM), University of the Philippines Los Baños (UPLB), University of Science and Technology of Southern Philippines (USTP), and Landcare Foundation of the Philippines (LFPI).

4 Objectives

Objective 1: To determine the key soil constraints that impact on vegetable production.

- Collate soil test data from existing sources and identify gaps in knowledge and data and review available literature.
- Conduct soil and plant surveys to identify key soil constraints in vegetable production soils in Leyte, Mindanao (north and south), Bohol, and Samar (Philippines), and a smaller set of samples in Australia.
- Develop and publish survey data for vegetable soils and identify key soil indicators for improving vegetable soil and nutrient management.

Objective 2: To compare production, soil fertility and economics of vegetable production from organic, conventional, and protected systems.

- Conduct research and demonstration trials to compare productivity and nutrient dynamics under different nutrient management strategies and production systems.
- Identify whether differences in food quality exist between organic or conventionally produced vegetables or other factors (eg. micronutrient limitations).
- Evaluate soil fertility changes over time in organic, conventional and protected cropping production.
- Evaluate the economics of fertiliser management in organic, conventional, and protected cropping production.

Objective 3: To develop improved and targeted site-specific nutrient management strategies.

- Experimentation to develop practices for sustainable and balanced nutrient management in vegetable systems.
- Evaluate impact of acid-soil infertility on vegetables.
- Evaluate micronutrient responses in vegetables.
- Evaluation of organic matter mineralisation to assess N release (mineralisation)
- Develop and extend knowledge of improved vegetable crop nutrient practices including demonstration trials conducted with stakeholder farmers, agricultural professionals, and advisers.

Objective 4: Assess the interaction between vegetable genetics and soil and nutrient limitations.

- Develop nutrient response profiles for crop species and cultivars within crop species.
- Produce knowledge and recommendations for nutrient management for specific vegetable cultivars.
- Evaluate and identify the sensitivity of vegetable crop species and cultivars to soil-acidity limitations (Al toxicity).
- Identify improved pepper genetics adapted to low soil fertility (including tolerance of Al toxicity, and high nutrient acquisition rates).

Objective 5: To deliver training and extension to advance soil and nutrient management skills in extension and research staff

- Conduct training in Philippines and Australia to improve research capacity and knowledge.
- Complete demonstration trials and field days, publish information and conduct training for nutrient management by smallholder vegetable farmers.
- Philippine project members visit Australia for science methodology and technology training.

5 Methodology

5.1 Soil fertility constraints to vegetable productivity

Field survey of key soil and nutrient constraints that impact on vegetable production.

A farmer engagement protocol was developed by Philippine Landcare Foundation to ensure the survey was supported by local communities and farmers, and to avoid any misconceptions and subsequent resistance from land owners/farmers. This community engagement protocol also ensured there was consistency in the engagement process and appropriate local formalities were understood and adhered to. The basis for the protocol is included in table 5.1. The survey evaluated soil and crop nutrition limitations in vegetable production systems in the priority areas of Leyte, North and South Mindanao, Bohol, and Samar.

Within each region vegetable farmers were identified to conduct the survey. The survey consisted of the collection of socio-economic demographic agronomic data from the farmer, along with soil and plant samples. The survey identified a minimum of 20 farmers from each region to participate in the survey. Full details of the survey are include in Appendix 11.1. A large range of information was collected but key information included, area (ha) of vegetables produced, planting density (plants/ha), crop yield, varieties grown, land preparation practices, nursery activities, planting windows etc. Details on the range of inputs was also collected including mineral fertilisers (types and rate), soil amendments (e.g. lime, compost, manure, compost tea) and rate of application.

Soil samples were collected from each vegetable farm according to a set procedure (Appendix 11.2) to ensure a representative sample was collected and from both surface soil (0-20 cm) and subsoil (20-40 cm). Soil samples were air dried and processed according to the protocol and prepared for analysis. The soil chemical properties analysed included pH, organic carbon, effective cation exchange capacity, base saturation, total N, available P, exchangeable bases (K, Ca, Mg, Na), exchangeable Al, and micronutrients (Fe, Mn, Cu, Zn). Soil physical properties including particle size distribution, bulk density, and total porosity were also determined for most samples. Depending on the temporal presence of vegetable crop, leaf samples were taken and analysed to assess mineral nutrient status.

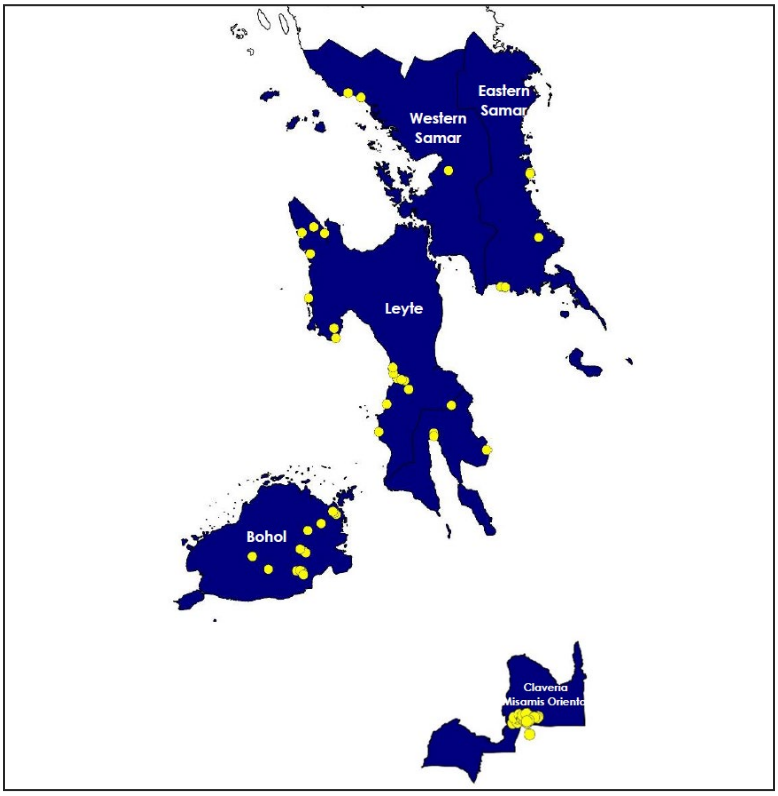


Figure 5.1. Sites in Claveria (Northern Mindanao), Bohol, Leyte (excluding Cabintan), and Samar where soil and plant samples were collected.

Table 5.1. Community engagement protocol for collecting survey data for soil and nutrient management.

<table>
<tr><th>Basic Processes</th><th>Specific Activities</th><th>Tool / Instruments</th><th>Remarks</th></tr>
<tr><td>Generating support of LGU (municipal) for conduct of the soil testing and other project interventions of the project in support of the small farmers.</td><td rowspan="4">Courtesy call and presentation of the project highlighting on the importance of soil testing
Request support to help explain the project to the constituents;
Request clearance to work closely with barangay officials and Tanod.</td><td rowspan="4">Project brochure indicating objectives and basic process and intervention and their benefits to the farmers and community</td><td>If needed we may at this stage negotiate with the LGU to extend counterpart contribution through;
Counterpart fund
Deployment of staff as Landcare focal person
Logistics Etc.</td></tr>
<tr><td>Generate list and mapping of sampling sites to include names of farm owners that will be affected</td><td>The list should include names of farmers and indicate whether or not they are the actual owners</td></tr>
<tr><td>Courtesy call and presentation of project to Barangay Officials and Tanods</td><td>Present also the map and sampling list.
Request the barangay official or Tanod to go through the list whether there are names in the list that may oppose the sampling.
From the list also request barangay official to indicate whether they are the actual land owner and whether or not there is still a need to seek permission from the land owner</td></tr>
<tr><td>Conduct house visit to explain to farmers whose farmlands will be covered by the soil sampling prior to the actual soil sampling</td><td>As much as possible explain the project in the presence of all mature persons in the household. We should not proceed with the sampling unless there is explicit approval of the head of the family</td></tr>
<tr><td colspan="4">Check list of important things to do during the first farmer visit:
Make sure that you are in the company of the barangay official who personally know the concerned farm owner
Introduce yourself and look for the head of the family politely
Start explaining your purpose with as many members of the family but always in the presence of the head of the family
Bring project brochure, business card with contact number
In the company of barangay Tanod and/or barangay official
Agree and set the specific date and estimated time of the actual sampling;
If you need to take pictures, seek first permission from the head of the family
It would help if the head or any member of the family can give one mobile phone number so they will informed in advance the actual time of the sampling; This is just to make sure that there are members of the family present during the actual sampling.</td></tr>
<tr><td>Actual Soil Sampling</td><td></td><td>Sampling Tools and instruments</td><td></td></tr>
<tr><td></td><td colspan="3">Check list of important things to do during the actual soil sampling:
Inform any member of the family before the soil sampling
Show any mature member of the family the sampled soil before leaving the vicinity</td></tr>
</table>

Nutrient omission trials (NOT)

The study was conducted at the Agricultural Systems Institute, UPLB, from July 2016 to February 2017; and at the research facility of the USTP, Misamis Oriental, from July to October 2017.

The first nutrient omission trial evaluated nutrient limitations in an acidic and calcareous soil using maize as the test species. The acidic soil was collected from Cabintan, Ormoc City, Leyte and classified as a non-allophanic Andisol (Asio, 1998). The calcareous soil was collected from Isabel, Leyte and was identified as from the Faraon series classified as Lithic Rendols Mollisol, characterised by dark-coloured surface horizon underlain by weathered limestone (Carating, 2014).

A further series of NOT were conducted on acidic soils of Claveria, Misamis Oriental using maize, sweet pepper, and cabbage as test species. The soil used was classified as a Jasaan clay, a Hapludults developed from basaltic andesitic volcanic material underlain by clay with highly weathered volcanic tuff and known to have good drainage.

A range of test species were used in the study including maize (*Zea mays*), sweet pepper (*Capsicum annuum*) and cabbage (*Brassica oleracea var. capitata*). Maize was initially chosen since it widely studied in upland cropping and is commonly used as a test plant because of its well-characterised responses to nutrient deficiencies, rapid growth, and uniform development from the seed (Bell, 2002; O'Sullivan, 1997). Importantly, in contrast to most vegetable crops maize has low incidence of major pests and diseases. As a C4 plant, it acquires and efficiently converts nutrient to biomass, thus can be considered as one of the most responsive crop to deficiencies in the tropics. Maize for grain production is expected to show a strong response to Zn and Fe with a medium response to Mn, Cu, and a low response to B and Mo under deficient conditions (Laboski, 2012).

Cabbage is one of the important vegetables produced in the acid upland soils of the Southern Philippines where temperatures are moderated by elevation. Studying its nutrient requirement and response provides relevant data on which nutrients critically affect yield. Most of the studies of vegetables in the Philippines are limited to N, P and K, making the study that includes crop responses to other micronutrients relevant and timely. Because of its high yield potential the nutrient demand for cabbage is high, particularly for N and K, and it often expresses Mo deficiency due to a relatively high demand (Nastor, 2015) as well as B.

Sweet pepper is a major crop in the Southern Philippines and correction of macro and micronutrient limitations is critical in maximising yield. Sweet pepper has a high requirement and response to N, P and Ca and a relatively high requirement for Mn, B, Zn and Fe intermediate requirement for Cu and a relatively low requirement for Mo (Weir and Cresswell, 1993).

The test treatments included the 14 different nutrient concentrations that were compared to the complete. These included: complete solution (+All) and complete solutions minus each of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Mo, Ni, and Co. For acid soils, additional treatment was obtained, lime plus complete solution (all+lime). The nutrient solutions used in the study were prepared based on the nutrient omission trial protocol of Asher et al. (2012). A preliminary trial on different levels of nutrient solution was conducted, to identify an initial 'best guess' for the appropriate application rate for each element. The best nutrient formulation was determined for each soil type following the procedure in the preliminary trial omission pot experiment conducted. Formulation was prepared as a stock solution, and computed to provide nutrients for 133 cm^2 and 254 cm^2 exposed area with a total weight of 1.5 kg and 5 kg of air-dried bulk soil per pot, respectively. The aliquot of stock for each element is presented in Table 5.2. Soil samples were air-dried and passed through a 5 mm sieve and added to the pot in polyethylene plastic bag liners. Soil moisture content of the soil samples at field capacity was determined.

Table 5.2. Computed amounts of salt needed for NOT stock solutions.

Element applied and rate (kg /ha)		Nutrient Form	Rate of nutrient form (kg/ha)	Stock solution concentration 5 ml (g/L) 133 cm^2	Stock solution concentration 10 ml (g/L) 254 cm^2
Macronutrients					
N	100	NH_4NO_3	286	180.35	
	100	Urea	214		54.55
P	80	NaH_2PO_4	173	108.69	
	80	Na_2HPO_5	367		93.31
K	80	KCl	161	101.42	40.92
Ca	35	$CaCl_2$	98	61.79	24.85
Mg	30	$MgCl_2$	250	157.5	63.74
S	25	Na_2SO_4	111	69.92	28.12
Micronutrients					
Fe	5	FeNa EDTA	32.9	20.77	8.36
Mn	5	$MnCl_2$	16.35	10.32	4.16
Zn	4	$ZnCl_2$	8.34	5.22	2.12
Cu	3	$CuCl_2$	8.04	5.05	2.05
B	2	H_3BO_3	11.4	7.17	2.91
Mo	0.4	$(NH4)_6 Mo_7O_{24}$	5.15	3.22	1.31
Ni	0.1	$NiCl_2$	0.405	0.26	0.10
Co	0.1	$CoCl_2$	0.404	0.26	0.10

The nutrient solutions were added from stock solution one at a time using clean glass pipettes for each stock solution. A 5 ml aliquot of each nutrient solution was added to pots, with the exception of Fe for which the aliquot was 7.5 ml, and distributed evenly to the 1.5 kg of soil. For the 5 kg pots a 10 ml aliquot of each nutrient solution was applied except for Fe which received a 15 ml aliquot. For the acidic soils (Cabintan and Claveria), where the pH was less than 5.0, a treatment with recommended amount of lime plus all the nutrients was included. Each treatment was replicated 3 or 4 times depending on the availability of soil. All of the pot experiments were conducted under controlled conditions, to minimise variability. The trial was established in screen house and plants grown for 45 days.

Hybrid fungicide treated seed of maize was sourced and two seeds sown in each pot. For cabbage about three seeds were sown in each pot. Pots were thinned to 1 plant per pot at 10 days after emergence. Sweet pepper plants were prepared as seedlings and transplanted to pots 2 weeks after emergence. Water was added to the pots regularly, based on the gravimetric moisture content at 80% field capacity.

Observations of plant response to possible nutrient deficiencies were conducted regularly. Throughout the growing period the changes in height, colour, appearance of visual symptoms, and growth of the test plants were observed and recorded as the basis of deficiency. Maize plants in the Cabintan and Isabel soils were harvested at 45 days after sowing. Maize, sweet pepper and cabbage biomass were harvested at 60 days after sowing in the Claveria trials. Final fresh and dry matter biomass was determined and recorded. The dried samples were wet-ashed and the nutrient content determined.

As a baseline in identifying the nutrient levels present in the soil the following parameters were analysed: soil moisture at field capacity, soil texture and soil pH, soil organic matter content, and macronutrients such as total N, available P, exchangeable K, exchangeable Ca, and exchangeable Mg. The Bray method for extracting available P in acid soils was used for soils from Cabintan and Claveria, while the Olsen extraction method was used for calcareous soil of Isabel. An ammonium acetate method was used for extracting the exchangeable K, exchangeable Ca, and exchangeable Mg. Exchangeable K was read using flame photometer while Ca and Mg were analysed using EDTA titration. Micronutrients, including Fe, Zn and Cu, were extracted in the soil samples through DTPA extraction procedure and analysed using AAS.

The experimental design was a Randomised Complete Block and analysis of variance was conducted to determine the treatment effects (micronutrients response) in each soil type using Statistical Tool for Agricultural Research (STAR) software developed by IRRI. Each treatment mean was compared with the ALL treatment using Tukey's Honest Significant Difference test. For nutrient uptake and the P use efficiency trials a pairwise mean comparison of each treatment combination was done.

Cabbage reference leaf survey

A divergent range of symptoms of nutrient limitations have been observed in vegetable crops in the Philippines and these have varied across crops, districts, and soil types. Diagnosis of nutrient disorders in these crops on the basis of visual symptoms alone is unreliable since symptoms are not usually expressed as classic (textbook) symptoms and plant tissue testing is required in attempting to definitively assess the limitation. Plant analysis for nutrients is a useful tool for assisting in the diagnosis of nutrient limitations and for optimizing rates of nutrient application. It is particularly useful for diagnosing micronutrient limitations where plant uptake (represented by plant tissue concentrations) is a more sensitive indicator for disorders than is the soil concentration of the nutrient. Furthermore, there is not always good correlation between the plant nutrient uptake and soil nutrient concentration. Plant tissue testing can be used to identify a general low nutrient status ("Hidden Hunger") or in some situations specific limitations where thrifty (healthy) and unthrifty (unhealthy) plants may be present within a field.

To diagnose potential nutrient disorders and nutrient limitations ("Hidden Hunger") in vegetable crops a survey protocol was developed. The full protocol is included in Appendix 11.2 and outlines a general survey method and a paired comparison method (poor and healthy plants) for diagnosing nutrient disorders. The survey was conducted across a range of farmer's crops using cabbage as a reference crop in the priority areas of Claveria, Cabintan, and Bukidnon. The aim of this survey was to identify the mineral status of cabbage crops that will assist in the identification and understanding of nutrient limitations. Depending on the availability, 10 to 20 samples were collected from each region. The samples were taken across a range of farms that have varying soil properties and use different crop input strategies. At each farm a representative sample reference leaves was collected from a minimum of 20 plants randomly selected from the cabbage crop. Samples were collected at about 56 days after transplanting and reference plant tissue was the youngest mature leaf blade (youngest mature wrapper leaf). Other information including soil and plant photos, GPS coordinates, and farmer practices were collected. In the field samples were stored in an icebox with ice, then taken to a laboratory and dried in the dehydrator (67^{o}C) and sent to Australia for analysis.

Effects of intensive vegetable production on N and P levels in an Andisol

The study was conducted in Barangay Cabintan located approximately 18 km northeast of Ormoc City in Leyte; a locality where intensive vegetable cropping is practiced. The soils were andesitic and dacitic volcanic deposits. Eleven vegetable farms and one secondary forest site were selected for soil sampling. Soil samples were collected from the 12 sites (Fig. 5.2) at depths of 0-20, 20-40, 40-60, 60-80, 80-100 cm. The soil samples were brought to the Department Soil Science, VSU, for processing and analyses. Soil samples were air-dried, pulverised using a wooden mallet, and sieved through a 2-mm screen to for the determination of most soil physical and chemical properties. For organic matter and N determination, sufficient sample was further ground and passed through a 0.425 mm screen.

Particle size distribution was determined using the Hydrometer method (ISRIC, 1995) after treating the sample with sodium hypochlorite to destroy organic matter and 1 M NaOH to disperse the soil and ultrasonic disintegration (Hielscher UP100H). Soil pH (H_2O and KCl) was analysed by the potentiometric method using a soil-water solution ratio of 1:2.5 (H_2O and 1M KCl) (ISRIC, 1995). One gram of soil was weighed into a 100 mL beaker. Then 50 mL of 1 M NaF was added and stirred vigorously using a glass rod for 1 min. The pH was read at exactly 2 min after adding the NaF solution whilst ensuring the suspension was well stirred immediately prior to taking reading (ISRIC, 1995). Soil organic matter was analysed using the modified Walkley-Black method (Nelson and Sommers, 1982). Total N was analsysed using the Kjeldahl method (ISRIC, 1995). Available P was determined using the Bray P-2 extraction method with 0.1 N HCl and 0.03 N NH_4F extractant (Jackson, 1958) and a UV Vis spectrophotometer at 880 nm wavelength.

After the analysis of both physical and chemical properties, all data were gathered and encoded in MS Excel. Depth function of each soil property were plotted. The values determined for each property were compared with the ranges in Landon (1991) to determine if they are low, moderate or high.

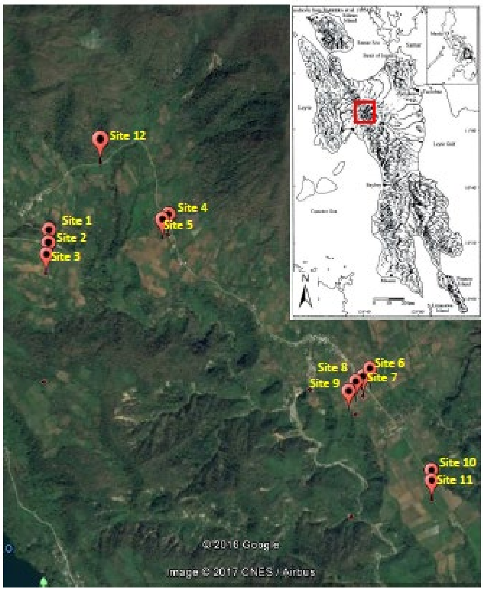


Figure 5.2. Map showing the location of the study site in Brgy. Cabintan, Ormoc City

Figure 5.3. Photograph from 1 to 12 shows the twelve sampling sites in Cabintan, Ormoc

5.2 Evaluation of organic production strategies for crop nutrition.

Field experiment comparing organic and conventional production practices

A sequential series of field experiments was conducted over a three year period at the BSWM Research Station in Malaybalay, Bukidnon to compare the productivity of a range of treatments that use conventional and organic principles. The soil type at the site is an Ultisol and soil chemical properties are presented in table 5.3. The experimental design was a randomised complete block (RCB) consisting of seven treatments and replicated four times. The seven treatments consisted of:

1. Control – No added fertilisers or amendments.
2. Full Organic production system [*in compliance with the Philippine National Standards on Organic Agriculture-PNS-OA*].
3. Full Conventional production system (*synthetic fertilisers and synthetic pesticides*).
4. Organic fertilisers combined with synthetic pesticides.
5. Synthetic fertilisers combined with biopesticides/bio-control agents.
6. A combination of synthetic fertilisers and organic fertilisers with synthetic pesticides.
7. A combination of synthetic and organic fertilisers with bio-pesticides/bio-control agents.

These experiments have been conducted on sweet pepper (1 cropping cycle), and tomato (2 cropping cycles), cabbage (2 cropping cycles), and eggplant (2 cropping cycles).

Prior to planting, weeds growing in the experimental area were removed and the trial area cultivated using a tractor and hills and furrows delineated using an animal drawn plough. Seeds were sown in seedling trays and transplanted at 25 days after sowing. The plant orientation was a 100 cm row spacing and a 50 cm within row plant spacing.

The organic fertilisers were applied to appropriate treatments (Treatments 2, 4, 6 and 7) at three weeks before transplanting while inorganic fertilisers were applied as four split applications including, at transplanting, flowering, after first harvest, and third harvest. The organic fertiliser used in the study was vermicast at the recommended rate of 8 t ha^{-1} and the inorganic fertilisers included urea (46-0-0), Solophos (0-20-0 N:P:K), and muriate of potash (0-0-50 N:P:K) to achieve 70-52-30 (N:P:K) kg ha^{-1}.

In T2, T5 and T7, biopesticides and botanical pesticides were used including Vermi-tea and Organic Herbal Nutrient. In T3, T4 and T6, commercially-available synthetic pesticides were used to control insect pests and diseases and included Karate (Lambda-Cyhalothrin), Brodan (Chlorpyrifos), Super insecticide and Manzate (mancozeb) and Atlas as a wetting agent. Hand weeding was done to control weeds. For tomato, plants were trellised at the early fruiting stage. The test crops grown over the duration of the experiment included tomato, sweet pepper, eggplant, and cabbage. Marketable and total yields were determined for each crop and assessments made of pest and disease incidence.

Response of vegetables to chicken manure application

A pot experiment was conducted at the VSU - Farmville Experimental Station to evaluate the effects of chicken manure rates (alone) on productivity of eggplant and associated soil properties. The site was located to the north of the City of Baybay (Leyte) with coordinates of 10°44’48’’N 124°48’27’’E. The rainfall is evenly distributed throughout the year without a distinct dry and wet season. The soil type is an Inseptisol with a texture 14% silt, 41 % clay, and 45 % sand, and a pH of 6.29.

Table 5.3. Selected soil properties for trial site at BSWM Research Station in Malaybalay, Bukidnon.

Properties	
pH H2O, 1:5	5.82
Avail. P, mg/kg	6.03
OC, %	2.47
OM, %	4.25
Total N %	0.25
Ca mg/kg	811
Mg mg/kg	459
K mg/kg	190
Na mg/kg	10.1
Exch. Ca cmol (+) per kg	4.05
Exch. Mg cmol (+) per kg	3.82
Exch. K cmol (+) per kg	0.48
Exch. Na cmol (+) per kg	0.04
EA, cmol/kg	17.4
CEC Sum	25.8
CEC, $cmol_c$/kg	17.2
Base Satn, % on CEC	48.8
Cu mg/kg	3.92
Zn mg/kg	1.78
Mn mg/kg	29.0
Iron mg/kg	196.

The experiment was laid out in a split-plot randomised complete block design with the levels of chicken manure as the main plots and the eggplant genotype as the subplots. Seven chicken manure treatments were imposed in combination with 2 varieties, each with four replications. Fourteen kilograms of soil sample was placed in each of 23cm x 23cm x 40cm polyethylene plastic bags. The chicken manure treatments included a Nil treatment (T1 no chicken manure) and chicken manure added at rates of 200 g pot^{-1}, 400 g pot^{-1}, 600 g pot^{-1}, 800 g pot^{-1}, 1,000 g pot^{-1} and 1,600 g pot^{-1}. At a typical plant population of about 12,500 plants ha^{-1} this equated to rates of about 2.5 t ha^{-1} (at 200 g pot^{-1}) to 20.0 t ha^{-1} (1,600 g pot^{-1}). The chicken manure and soil in each bag was mixed thoroughly.

Seedlings of the two main Philippine eggplant cultivars, Moreno and Casino, were prepared in seedling trays and at 30 days after sowing transplanted individually into each pot. The chicken manure was purchased locally and contained 10% moisture. A composite sample of the manure was dried and analysed, and data presented in table 5.4 along with estimated equivalent rates of mineral application per ha per treatment.

Table 5.4. Mineral concentration of chicken manure and equivalent mineral application rates (kg ha^{-1}) for a pot experiment conducted at Visayas State University.

Mineral concentration		Estimated rate of mineral applied (kg ha^{-1}) at each chicken manure treatment (t ha^{-1})					
		2.5 (T2)	5.0 (T3)	7.5 (T4)	10.0 (T5)	12.5 (T6)	20.0 (T7)
N (%)	3.2	72	145	218	291	364	583
P (%)	8.3	186	373	560	747	933	1494
K (%)	4.2	94	189	283	378	472	756
Ca (%)	2.2	49	99	148	198	247	396
Mg (mg kg^{-1})	687	1.5	3.0	4.6	6.1	7.7	12.3
Fe (mg kg^{-1})	6,020	13	27	40	54	67	108
Mn (mg kg^{-1})	875	1.9	3.9	5.9	7.8	9.8	15.7
Cu (mg kg^{-1})	320	0.7	1.4	2.1	2.8	3.6	5.7
Zn (mg kg^{-1})	273	0.6	1.2	1.8	2.4	3.0	4.9

The horticultural and yield data were collected, including the number of days from transplanting to flowering and first harvest, plant height at harvest, number and weight of marketable and non-marketable fruits, fruit weight, fruit size, total yield. The food quality of harvested eggplant fruit was assessed based on the measurement of electrical conductivity (EC), free radical scavenging activity (Fang *et al*., 2002; Marxen *et al*., 2007), oxidation-reduction potential (ORP), pigment composition (Dere *et al.,* 1998), total dissolved solids (TDS) and vitamin C content. A further component of the study evaluated the effects of the different chicken manure treatments on soil properties including soil pH, organic matter, total N, available P, exchangeable K, and some micronutrients including Cu and Zn. Furthermore, the concentration of mineral nutrients was determined and related to yield of eggplant.

Effects of chicken manure and liming on sweet pepper on an acidic Andisol.

A further pot experiment was conducted to evaluate the effects of lime and chicken manure on growth of sweet pepper. A bulk Andisol soil sample (0-20 cm) was collected from Barangay Cabintan, Ormoc City, Leyte and air-dried in a screen house at VSU. The soil was then pulverised and sieved using a 4 mm wire screen to remove clods. A further 1 kg of the soil was set aside and sieved through a 2-mm wire mesh for the determination of the initial soil chemical and physical properties.

The experiment was set up as a split plot design with three replications. The main plots were the liming treatments (± lime) and the subplots were the chicken manure rate treatments in combination with mineral fertiliser treatments (Table 5.5).

The horticultural and yield data were collected including, number of days from transplanting to flowering and first harvest, plant height at harvest, number and weight of marketable and non-marketable fruits, fruit weight, fruit size, and total yield. Results were analysed using the STAR computer software. Each parameter was tested for differences using analysis of variance (ANOVA) and comparison of means was tested using Tukey's Honest Significant Difference Test.

Table 5.5. Treatments imposed in a pot experiment at Visayas State University evaluating effects of chicken manure and lime on sweet pepper growth.

Code	Treatment
T_0	Control
T_1	200N:65P:83K kg ha^{-1}
T_2	5 t ha^{-1} chicken manure
T_3	7.5 t ha^{-1} chicken manure
T_4	12 t ha^{-1} chicken manure
T_5	100N:33P:42K kg ha^{-1} plus 5 t ha^{-1} chicken manure
T_6	100N:33P:42K kg ha^{-1} plus 7.5 t ha^{-1} chicken manure
T_7	100N:33P:42K kg ha^{-1} plus 12 t ha^{-1} chicken manure

5.3 Nitrogen response experiments

Eggplant and sweet pepper - Leyte

A field experiment was conducted at the VSU - Farmville Experimental Station on an Inceptisol of pH 6.29 to evaluate the response of two eggplant cultivars to N application rates.

An area of about 44m x 13m (572 m^2) was ploughed and harrowed twice and divided into plots. Buffer beds of 1 m width were imposed between all treatment plots. Prior to planting soil samples (0–20 cm depth) were taken and analysed for physical and chemical properties using standard laboratory methods as previously described. The experiment was laid-out in a split-plot with seven treatments, two cultivars and four replications giving a total of 56 sub-plots. The N fertiliser rates were allocated as the main plots and eggplant cultivars as sub-plots. The N treatments included 0 (T1), 50 (T2), 100 (T3), 150 (T4), 200 (T5), 250 (T6) and 300 (T7) kg N ha^{-1}. Adequate rates of P (45 kg P ha^{-1}) and K (133 K ha^{-1}) were applied to achieve maximum yield. The N fertiliser treatments were applied as four split applications to achieve the N rates. The first, second, third, and fourth applications were done at transplanting, 3 weeks, 5 weeks, and 7 weeks after transplanting. The forms of N, P, and K included urea, calcium nitrate, single superphosphate, and muriate of potash.

Seed of two eggplant cultivars (cvs. Moreno and Casino) were sown in trays containing a mixture of garden soil, vermi-compost and carbonised rice hull at a ratio of 1:1:1 by volume. At 4 weeks after sowing the seedlings were transplanted to the experimental plots at a spacing of 0.5m x 0.5m in 30cm raised beds with 20 plants per plot. All standard cultural management practices for eggplant production were followed including staking, pruning, weeding, irrigation, and control of insect pests and diseases.

Bulk surface soil samples (0-20 cm) were taken after land preparation. At the vegetative stage and at final harvest, soil samples from each treatment plot were collected to identify changes in soil fertility. The samples were air dried for 2-3 days then pulverised and sieved through a 2-mm wire mesh. Soil chemical properties were determined as previously described.

The data for yield, food quality and soil and nutrition were collected as described in the previous VSU experiments. Analysis of variance was conducted using STAR software to determine the significance of results and the differences between treatments were assessed using the Tukey's Honestly Significant Difference at 5 % level.

Table 5.6. List of experiments conducted at USTP Claveria under SMCN-2012-029.

Crop	Varieties	First cropping	Second cropping	N rates applied	Plant spacing	Comments
Tomato	Harabas and AVTO 1173	July-Sept 2016	Jan-April 2017	0, 50, 100, 150, 200 and 250	2 row bed (1.5m width) 50cm row x 50cm plant spacing	
Cabbage	Resist Crown and KEX -734	July-Sept 2016	April-June 2017	0, 50, 100, 150, 200, 250 and 300	2 row bed (1.0m width) 50cm row x 40cm plant spacing	
Lettuce	Leafy and Heading	July-Aug 2016	Sept–Oct 2016	0, 50, 100 and 150	2 row bed (1.0m width) 40cm row x 30cm plant spacing	Open field
Lettuce	Leafy and Heading	July-Aug 2016	July-Aug 2016	0, 50, 100 and 150	2 row bed (1.0m width) 40cm row x 30cm plant spacing	Protected cropping
Cabbage	Resist Crown and KEX -734	Jan-March 2017	Jan-Mar 2017	0, 50, 100, 150, 200, 250 and 300 And Farmer’s practice	2 row bed (1.0m width) 40cm row x 40cm plant spacing	

This experiment was repeated for sweet pepper using the same N treatments and methodology and with two sweet pepper cultivars (cvs. Emperor and Sultan). The data collection was as for the eggplant N rate experiment.

Tomato, cabbage and lettuce N response experiments - Claveria

A series of N response experiments were conducted at the Agricultural Experimental Station of University of Science and Technology of Southern Philippines and a grower's field in Claveria. The experiments were conducted on tomato, cabbage, and lettuce (Table 5.6). The experiments were conducted as factorial combinations of N rate and variety (Table 5.6) using a split plot design with N rates as the main plots and varieties as the sub-plots with each factorial treatment being replicated four times. For each experiment a sterilised soil mixture of garden soil, vermicast, lime, and sand (ratio of 4:5:½:1) was prepared and seedlings grown in a protected screenhouse until ready for transplanting. Seedlings were transplanted at about four to five weeks after sowing at planting densities as per Table 5.6. Crop preventive spraying was conducted to manage pests and diseases.

In each experiment a basal application of bio-organic fertiliser Wellgrow™ (1.1:1.24:1.34 of N-P-K, 5.78% Ca, 0.87% Fe, 0.019% Cu, 8.312 mg kg^{-1} Mg, 927 mg kg^{-1} Mn, and 339 mg kg^{-1} Zn) at 20 g per plant was made to all plots. A "complete" fertiliser (14.0:11.6:6.1) was applied at a rate of 10g per plant to all plots receiving 50–300kg N ha^{-1} while the 0kg N ha^{-1} trial received Wellgrow only. Urea, solophos (0:20:0) and muriate of potash (0:0:50) used as sources of N, P, and K, respectively to achieve the N treatments and to supply a total of 44 kg P ha^{-1} and 133 kg K ha^{-1}. The fertiliser was divided into 3 or 4 split doses (depending on the N rate and crop species) applied at transplanting, 21 days after transplanting (DAT), 35 DAT, and 49 DAT.

For tomato, the first harvest was done at 55 DAT and four weekly harvest were completed. The tomato fruit were harvested at the mature green stage and divided into marketable and non-marketable fruit. Data was collected on days to flowering, plant height and stem diameter, plant survival, and fresh and dry matter yield. Dry matter samples were oven dried at 70˚C for 24 hours or until a constant weight was achieved. Fruit yield (including marketable and unmarketable yield) and fruit number average fruit weight (g) and fruit size (mm) (polar and equatorial) were also determined. Postharvest quality was evaluated including shelf-life, visual quality rating, and weight loss and shrivelling.

For cabbage, fertiliser was applied as 3 split applications. Harvesting was done at 61 DAT when the head was full and compact. For the second cropping, cv. KEX–734 was harvested 7 days earlier than cv. Resist Crown. Data was collected on days to heading, plant stand, and, fresh and dry matter yield. Dry matter samples were oven dried at 70˚C for 24 hours or until a constant weight was achieved. Yield and yield components were determined, including, number and weight of marketable and non-marketable heads per plot, head weight (g), head size (cm) (polar and equatorial length), and yield (marketable and unmarketable) (t ha^{-1}). Postharvest quality was evaluated including shelf-life, visual quality rating, weight loss and shrivelling. The initial weight of the cabbage head and the weight at each sampling period was determined. Weight loss was expressed as a percentage of the initial weight.

Analysis of variance (ANOVA) was used to test significance among treatment means using Assistat (version 7.0 beta). Tukey's test was used to compare the significant differences among means.

Bunching onion response to N application - Australia

A field experiment was established in the winter production season in the Lockyer Valley (Queensland Government DAF Gatton Research Facility) aimed at identifying the optimal N requirements for bunching onions (*viz.* Japanese Bunching Onions). Prior to planting, the trial site was planted to forage sorghum and the forage sorghum was cut, bailed and removed from the site to minimise soil residual nitrate levels and to ensure the site was uniform with respect to soil mineral N status.

The experimental design was a split-plot with 4 replicate blocks. Six N treatments were imposed including 0, 40, 80, 120, 160, and 200 kg N ha^{-1}. And this was applied predominantly as nitrate (80%) and ammonium (20%). A further series of N treatments evaluated effects of N form and included urea (100%), ammonium (80% ammonium 20% nitrate) and mixed nitrate (50%) and ammonium (50%) treatments each of which was applied at 120 kg N ha^{-1} and 160 kg N ha^{-1}. The N treatments were the main plots and sub-plots included 2 cultivars (cvs. Paragon and Zoolander). The main plot dimensions were 6 m by 3.0 m. A buffer of 1.0 m was imposed between N treatment plots in each bed to prevent cross-contamination of N between treatments. Furthermore, between the planted beds there was a full unplanted buffer bed that was not fertilised. The N treatments were applied in 4 applications as dissolved aliquots directly to each treatment replicate via a nutrient injection canister through drip fertigation. At planting, 80 kg K ha^{-1} was applied as sulfate of potash and the soil is inherently very high in P.

Applications of known potentially limiting micronutrients was applied to the whole trial via drip irrigation and included 0.8 kg Zn ha^{-1} as zinc sulfate heptahydrate, 0.8 kg B ha^{-1} as Solubor, and 0.3 kg Mo ha^{-1} as sodium molybdate. Irrigation, pesticide and herbicide were applied as required. Prior to planting a bulked representative soil sample was taken from each of the 4 blocks, dried at 40°C and held for analysis as required.

At 7 days after the final N application a reference leaf sample was collected from each treatment for each variety. After each N application, soil samples were taken from all the 120 and 160 kg N ha^{-1} treatments at approximately 0, 1, 2, 3 and 5 days and soil nitrate and ammonium extracted using 1M KCL. The samples were frozen immediately and held for analysis. The whole bunching onion plants were harvested at 13 weeks after planting and subsamples taken. The subsamples of each treatment replicate for each variety were dehydrated at 78°C and the dry matter concentration determined. The samples were held for analysis as required. To identify the effects of N rate and form on foliage colour and colour intensity a further series of fresh samples (3 leaves) were collected and held for chromatographic analysis conducted using a Minolta chromatographer. To further assess the relationship between N form and rate and foliage colours a UAV-drone with high resolution cameras was flown over the trial at harvest to image the experimental effects.

5.4 Effects of phosphorus biofertilisers and micronutrients on cabbage.

Phosphorus and biofertiliser effects on Cabbage.

Two field experiments were conducted in the Municipality of Claveria, Misamis Oriental from April to July 2017 to evaluate the effects of P, organic amendments, and microbial inoculants on the production of cabbage. A general description of the soil in the experimental site is presented in Table 5.7. A further third field experiment conducted in 2018 evaluated effects of micronutrients and biofertiliser effects on cabbage production.

Table 5.7. General description of the soil sampled from the experimental site at Claveria, Misamis Oriental.

PARAMATER	DESCRIPTION*
Parent Material	Basaltic andesite volcanic materials
Soil Order	Ultisol
Soil Series	Jasaan
Soil Texture	Clay
Soil Type	Jasaan Clay
Soil Taxonomic Classification	Typic Hapludults

*Carating, et al. (2014)

Key soil properties are presented in Table 5.8. The site was characterised by low pH particularly in the 20-40 cm zone and strong buffer acidity. Furthermore, soil organic matter, total N, and, exchangeable Ca and Mg were low, available P was very low and exchangeable K intermediate.

Table 5.8. Pre-plant soil analysis data for samples taken from 0-20 and 20-40 cm profile zones at a trial site in Claveria, Misamis Oriental.

PARAMETER	SOIL DEPTH		RATING/DESCRIPTION*
	0-20 (cm)	20-40 (cm)	
Soil pH (H_20), 1:5	5.20	5.02	Strongly Acidic
Soil pH ($CaCl_2$),1:2	4.65	4.50	Very Strongly Acidic
Soil Organic Matter (%)	3.33	2.74	Low
Total N (%)	0.11	0.08	Low
Available P (mg kg^{-1})	4.37	3.80	Very Low
Exchangeable K ($cmol_c$ kg^{-1})	0.39	0.28	Medium
Exchangeable Ca ($cmol_c$ kg^{-1})	3.67	2.78	Low
Exchangeable Mg ($cmol_c$ kg^{-1})	0.41	0.28	Low

*Adapted from PCAARRD (2013)

The two experiments were conducted during 2017 (March to July) and the experimental design was a Randomised Complete Block Design replicated four (4) times. In Experiment 1 the effect of P rates and MykoPlus (MyP) was evaluated and the treatments included Control (T_1 – No Fertiliser or Amendment), 0 kg P ha^{-1} (T_2), 0 kg P ha^{-1} + MyP(T_3), 22 kg P ha^{-1} (T_4), 22 kg P ha^{-1} + MyP (T_5), 44 kg P ha^{-1} (T_6) and 44 kg P ha^{-1} + MyP (T_7). All treatments received 150 kg N ha^{-1} and 133 kg K ha^{-1}. In Experiment 2 the effects of Organic Amendments and MykoPlus was evaluated and treatment details are included in Table 5.9.

Table 5.9 Treatments included in Experiment 2 evaluating the effects of mineral fertiliser, organic amendments and MykoPlus (MyP) conducted at Claveria, Misamis Oriental

Treatment Number and Name		Amendment (t ha^{-1})	NPK (kg ha^{-1})
T_1	Control (No Fertiliser and Amendment)	0	0:0:0
T_2	Recommended Rate of Inorganic Fertiliser (RRIF)	0	160:44:133
T_3	RRIF and MyP	0	160:44:133
T_4	Chicken manure (CM)	5	0:0:0
T_5	CM and MyP	5	0:0:0
T_6	CM and RRIF	5	160:44:133
T_7	CM and RRIF and MyP	5	160:44:133
T_8	Well-Grow	3	0:0:0
T_9	Well-Grow and MyP	3	0:0:0
T_{10}	Well-Grow and RRIF	3	160:44:133
T_{11}	Well-Grow and RRIF and MyP	3	160:44:133

The chemical analysis of the various soil amendments used in the experiment is presented in Table 5.10. The chicken manure and Well-Grow (an organic fertiliser widely used in Claveria) were applied as amendments whilst the vermicast was used as a growing medium for cabbage seedling preparation.

The experimental area was ploughed, harrowed twice and lime applied at 3.5 t ha^{-1} one week before planting. Plots were 12 m^2 (6 m x 2 m) and a buffer of 0.5 m was maintained between plots and blocks. Cabbage seed (cv. Resist Crown) was sown in seedling trays with Vermi-compost as the media and covered lightly with soil. The seedlings were grown under partial shade for the first three weeks. To minimise transplanting shock, the seedlings were hardened by decreasing the watering frequency and by exposing them to full sunlight for one week prior to transplanting. At 28 DAT seedlings were transplanted onto beds of 1 m width and a configuration of 40 cm by 40 cm. For the mineral fertiliser treatments, N was applied as urea in 3 split applications at planting, 20 DAT and 40 DAT. Phosphorus was added as solophos (0:20:0) and K as muriate of potash (0:0:50) both of which were applied at planting as were the applications of the organic amendments.

Table 5.10. Nutrient content of chicken manure, Well-grow and vermicast used in the field trials on cabbage.

ORGANIC AMENDMENTS	N (%)	P (%)	K (%)	OC (%)	C:N RATION
Chicken Manure	1.60	1.93	2.64	11.50	7.20
Well-Grow	1.53	2.12	3.33	9.50	6.21
Vermicast	1.81	0.52	1.51	8.48	4.69

A 300g packet of MykoPlus was first mixed with vermicast before putting the growing media in the seedling tray. The second application was done at 25 days after sowing (DAS) by drenching the seedlings with a mixture consisting of 300g of MykoPlus in 2L of water. After transplanting, seedlings were sprayed with a mixture of 300g MykoPlus in 16-32 litres of water using a knapsack sprayer at 14 DAT and 21 DAT.

Cabbage heads were harvested at 7 to 8 weeks after transplanting when the heads were fully formed. Five plants were randomly selected and head fresh weight (g), number of head leaves and head dimensions (polar and equatorial) were determined. The total yield for each plot and was converted to t ha^{-1} using a plant population of 56,250 plants ha^{-1}.

Soil samples were collected prior to planting and after harvest and analysed for pH (1:5 soil:H_20 and 1:2 soil:$CaCl_2$), soil organic matter, total N, available P and exchangeable K, Ca and Mg. The organic amendments were also analysed for total N, P, K, organic carbon and C:N ratio. At harvest, plant samples were collected, prepared and analysed for total N, P and K.

Data was analysed by ANOVA using STAR 2.0.1. Differences between treatment means were compared using Tukey's HSD test at 5% level of significance.

Micronutrient and biofertiliser effects on cabbage.

The third field experiment was conducted at the USTP in Claveria Misamis Oriental from July to November 2018. The field trial was a Split Plot design with the main plots consisting of the biofertiliser treatments including No Biofertiliser (B1), MykoPlus (B2) and Nutrio (B3). Sub-plots included combinations of fertiliser rates based on the RRIF and micronutrients (Table 5.11). Treatments T9 and T10 were included to verify whether Biofertilisers can reduce the rate of N fertiliser whilst T11 is the standard farmer's practice in Claveria.

The mineral fertilisers were applied as per the previous 2 biofertiliser experiments Micronutrients were applied as foliar sprays at 30 and 45 DAT. Boron was applied as 0.20% boric acid solution, Zn as a 0.5% zinc sulfate heptahydrate solution, Mo as a 0.1% ammonium molybdate solution, and Cu as 0.20% copper sulfate pentahydrate solution. Application of the chicken manure was done at transplanting at the rate of 5 t ha^{-1}. A 300g packet of MykoPlus was mixed with the growing media in the seedling trays and again applied at 14 and 21 DAT as a foliar spray. Nutrio was applied as a foliar spray at 14 and 21 DAT. The harvest and statistical analysis were as per the previous two experiments.

Table 5.11. Treatments included in Experiment 3 evaluating the effects of mineral fertiliser, organic amendments and micronutrients conducted at Claveria, Misamis Oriental.

Treatment code and details	
T_1	Control
T_2	RRIF (150N:44P:133K kg ha^{-1})
T_3	RRIF + B
T_4	RRIF + Zn
T_5	RRIF + Mo
T_6	RRIF + Cu
T_7	RRIF + B + Zn
T_8	RRIF + B + Zn + Mo + Cu
T_9	N:P:K - 75:44:133 kg ha^{-1} (half the RRIF N rate)
T_{10}	N:P:K - 75:44:133 kg ha^{-1} + B + Cu + Zn + Mo (half the RRIF N rate)
T_{11}	RRIF + Chicken Manure
T_{12}	RRIF + Chicken Manure + B + Cu + Zn + Mo

5.5 Studies on root system performance

Solution culture studies on effects of Al and pH on Pythium infection.

A series of solution culture experiments were conducted to evaluate the effects of soil solution properties on the growth of a range of vegetable species and accessions. This research principally looked at the effects of pH and Al^{3+} concentration on root growth and the influence of these in the expression of the soil borne pathogen Pythium. The experiments were conducted at the Queensland DAF Gatton Research Facility and UQ Gatton campus.

Effects of pH, Al, and Pythium on bean roots.

Initially, the direct effect of pH *per se* on bean root growth was assessed to identify the acidity response of bean. The range of pH values included 4.2, 4.5, 4.8, and 5.1. A volume of stock dilute nutrient solution was prepared using deionised water sufficient to achieve the range of imposed treatments (generally in the order of 15-20 L). The dilute nutrient stock solution was prepared to achieve the following nutrient solution concentrations (µM): N 1350 (NO_3 1250 plus NH_4 100), Ca 500, K 250, Mg 200, S 200, Fe 10, B 3, P 1, Zn 1, Mn 0.5, Cu 0.1, Co 0.04, and Mo 0.02 (Kerven *et al.* 1991).

For the pH experiment, the stock solution was then decanted into four 10 L buckets and the pH adjusted to 4.2, 4.5, 4.8, and 5.1 using 0.1M HNO_3 and 600 ml decanted into 700 ml borosilicate glass beakers. The beakers were covered with 120x120 mm plastic plates of 3 mm thickness in which five 20 mm equidistant holes were drilled. Into each hole a 20 mm plastic plug was inserted and each plug had a 2.5 mm hole in its base to allow the protrusion of the seed radicle into the solution.

For the Al experiment, a range of Al treatments were imposed to identify the Al toxicity threshold for bean roots. This included concentrations of 0, 5, 10, 15, 20, and 30 µm Al and pH was adjusted to 4.5 with each treatment replicated 4 times.

The test species in both experiments was Green Bean (*Phaseolus vugaris*) cv. Prairie. Seed was germinated at 25^0C using a moistened rolled cloth towel method. When the average radicle length was about 30 mm, one seedling was placed in each of the five plastic plugs inserted in each plate of each beaker and the beakers then placed on a laboratory bench at 24°C under artificial lighting. An aeration tube was inserted in the centre hole of the plate to about 2 cm from the bottom of the beaker. After 4-5 days growth, the plates with intact plants were sequentially removed from the solutions and the length of the taproot and root fresh weight determined for each plant.

For the Al experiments solutions were similarly prepared. The initial pH for the bulk stock solution was 4.5 and aliquots of 10 mM $AlCl_3.6H_2O$ were added to solutions to achieve total Al concentrations of 0, 5, 10, 15, 20, and 30 µm. A set of 4 beakers (replicates of each treatment) were prepared by decanting 600 g of each solution.

The experiments ran for 5 days after which plants were harvested and the length of root, and, root and shoot fresh weight determined for each plant.

Pythium Isolation

Pythium was cultured on petri dishes filled with agarose (PCA). The inoculated dishes were then stored in a dark cupboard away from plant material or other sources of contamination. When the Pythium culture had grown to the edges the plate (about 5 days) the culture was used to inoculate the pH or Al treated solutions. The inoculation of the dilute nutrient solution was added as an amount of 0.5 plate per beaker (i.e. one replicate). A portion of the plate was cut out, added to a solution, and blended until the agar was of a consistent colloidal suspension.

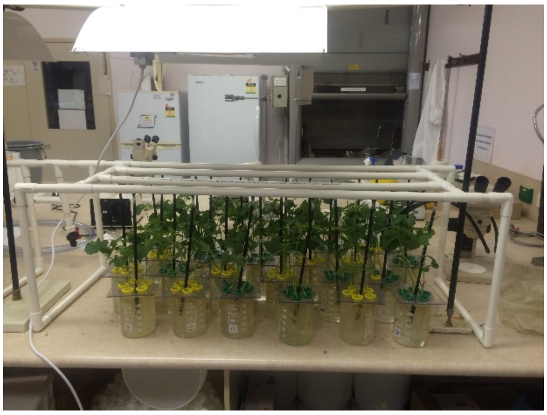
pH, Al, and Pythium effects

The first experiment on Pythium evaluated the effects of combinations of pH and Pythium on bean growth. The nutrient solution and Pythium cultures were prepared as above. The first experiment investigated pH values of 4.2, 4.5, 4.8, and 5.1 in combination with and without Pythium culture. A further series of experiments evaluated the effects of Al concentration in the presence or absence of Pythium inoculum. The Al concentrations imposed were 0, 10, 20, and 30 µm in factorial combination with or without Pythium inoculation. To allow sufficient infection period these experiments ran for 10 days.

Capsicum root system performance studies

A laboratory experiment was conducted to evaluate the effects of Al and pH on the growth of two commercial capsicum species (Warlock and Plato). The materials and methods used in this experiment were essentially the same as described for bean with the exception of the solution pH treatments (4.2, 4.5, 4.8, and 5.1), the Al treatments (0, 10, 20, and 30 µm) and plants were grown for a period of 12 days.

A further glasshouse experiment evaluated the effects of solution pH (4.2, 4.5, 4.8, 5.1, 5.4, and 6.0) on the growth of roots of 8 accessions of *Capsicum chinense* (16-5, 40-5, 42-3-1, 45-1-2, 46-1, 69-3, 71-3-1, and 71-3-3) identified by DAF as conferring high productivity when used as a grafted rootstock. Two commercial cultivars (Warlock and Plato) were also used as standard cultivars for comparison. The experiments were conducted in 30 l dilute nutrient solution (as stated above) and were grown for a period of 14 days.



Solution culture experiment capsicum

Clean polythene buckets were near-filled with about 22 L of deionised water and covered with plastic lids. Initially stock solutions were added to achieve the following basal nutrient solution concentrations (µM): N 1350 (NO3 1250 plus NH4 100), Ca 500, K 250, Mg 200, S 200, Fe 10, B 3, P 1, Zn 1, Mn 0.5, Cu 0.1, Co 0.04, and Mo 0.02. The solution level was made up to 2 cm below the bucket surface (≈25 l). Subsequently, nutrients were added as weekly applications of dissolved aliquots of nutrient solution based on a combination of forecast relative growth rate and solution nitrate and K concentration. Aeration tubes were inserted to the base of the pot and solutions were aerated using a portable aquarium aerator. The solution pH was maintained at 6.0 over the duration of the experiment. The experiment evaluated the growth responses of a standard capsicum (*Capsicum annuum*) cv. Warlock grafted over 6 accessions from the Queensland DAF *Capsicum chinense* germplasm collection (including 40-5, 42-2, 42-3-2, 45-1, 71-3-1 and 71-3-3) and a standard control of cv. Warlock grafted over the rootstock of cv. Warlock. The experiment was conducted as a randomised complete block with 4 replicates. The experiment was harvested 49 days after transplanting and the plants divided into foliage and fruit, and, each component weighed with the number of fruit recorded. The fresh samples were dehydrated at 70°C for 2 days and dry weight determined. The data was analysed ANOVA.

Potted soil experiment capsicum.

This glasshouse potted soil experiment was run concurrently with the solution culture experiment and evaluated the growth responses of a standard capsicum (*Capsicum annuum*) cv. Warlock grafted over 11 accessions of *Capsicum chinense.* The pots were watered using the inverted self-watering bottle technique of (Hunter 1981), which ensures soil moisture is adequate at all times. The experiment was established using 25 L black non-draining polythene pots lined with a sleeve of capillary matting to act as a wick to ensure the self-watering bottle technique provided even soil-water distribution. On one side of the sealed pot, a 50 mm sleeve of perforated PVC, of length the same as the pot depth. The sleeve was inserted into the pot between the capillary matting and pot wall and the pot filled with 22.0 kg of air-dried sieved (to 10mm) Vertosol soil (collected at 27°32'S; 152°22'°E). A sleeve of silver sided Sislation™ building insulation paper was placed around each pot to moderate soil temperature. Scions of cv. Warlock were grafted over 11 accessions from the Queensland DAF *Capsicum chinense* germplasm collection (including 16-5, 40-5, 40-6, 42-2, 42-3, 45-1, 46-1, 69-3, 71-2-1, 71-3-1, and 71-3-3) and a standard control of cv. Warlock grafted over itself. Nutrient rates equivalent to 155 N, 137 K, 80 Ca, and 50 S (as kg element ha^{-1}) were applied on a per plant basis using a plant population of 44,400 plants ha^{-1}. The nutrients were applied in three doses as dissolved aliquots in the self-watering bottles. Zinc (as $ZnSO_4.7H_2O$) and B (as H_3BO_3) were each applied at 300 g ha^{-1} equivalent (on an elemental basis) and Mo (as $Na_2MoO_4.2H_2O$) was applied at a rate of 15 g ha^{-1} equivalent (on an elemental basis). The experiment was conducted as a randomised complete block with 4 replicates. Harvest details were as per the solution culture experiment.

6 Achievements against activities and outputs/milestones

Objective 1: To determine the key soil constraints that impact on vegetable production.

No.	Activity	Outputs/ Milestones	Completion date	Comments
1.1	Collate soil test data from existing sources and identify gaps in knowledge and data and review available literature. (PC and A)	Data collated from existing Philippine knowledge bases and presented and reviewed by project team.	01/2015	A review of the available data from the Philippines highlighted that there was essentially no data on vegetable soil fertility. Limited data collected from the BSWM consisted of only a few soil samples that could not be directly related to vegetable production. In the Queensland component a substantial amount of soil and plant tissue test data has been assembled over a 25 year period.
1.2	Conduct surveys to identify key soil constraints in vegetable production soils in Leyte, Mindanao (north and south), Bohol and Samar and Qld. (PC and A)	Protocol for soil and vegetable crop surveying activity completed and reviewed across the survey teams and training completed. Completion of the soil and vegetable crop surveys in the priority areas of Mindanao, Leyte, Bohol and Samar. Completion of analysis of soil and plant survey samples and project team review of data.	01/2015	In the Philippines a substantial number of soil and plant samples (~300 samples) were collected from the priority areas of Leyte, Mindanao (Claveria and Davao), Bohol and Samar. The details of this are reported in the key results and discussion. In Australia, a relatively small number of supplementary samples were taken from the Stanthorpe, Bowen and Lockyer Valley areas of Queensland. This included about 90 soil samples and about 55 plant tissue samples across a range of vegetables (including capsicum, lettuce brassicas, bunching onion and garlic). Key inferences from the data highlighted Lockyer Valley soils had relatively low nitrate concentrations compared with Bowen soils. Soils in both Bowen and Lockyer Valley had inherently high P status. Soils in Bowen and Lockyer Valley had high Zn status (> 4 mg kg^{-1}) whilst the Boron status for these was relatively marginal (Lockyer valley mean B concentration 0.9 mg kg^{-1} and Bowen 0.4 mg kg^{-1}). The aggregated results for plant tissue analysis across all crop types showed high variability in all analytes indicating site specific and crop differences. Low and high status for all micronutrients was observed.
1.3	Develop and publish survey data for vegetable soils and identify key soil indicators for improving vegetable soil and nutrient management. (PC)	Completion of soil and plant survey regions on impacts and management.	08/2015	After discussions at the October 2015 project meeting it was decided to increase the number of samples in the survey to ensure that the survey data can be published. A paper is in preparation (VSU) which will include all data from Leyte, Samar, Bohol, Claveria and Bukidnon. The survey findings have been extended to small farmers to allow them to understand their soil and nutrient constraints.

PC = partner country, A = Australia

Objective 2: To compare production, soil fertility and economics of vegetable production from organic, conventional and protected systems.

No.	Activity	Outputs/ Milestones	Completion date	Comments
2.1	Conduct research and demonstration trials to compare productivity and nutrient dynamics under different nutrient management strategies and production systems. (PC)	Completion of trials, data reviewed and findings reported. Completion of sampling and analysis, review of data and reporting. Demonstration trials conducted with stakeholder farmers. Farmer field days and training schools held. Completion of fertiliser and productivity economic analysis and presentation of results at farmer field schools.	12/2016 06/2016 12/2016 02/2017	The aim of this objective was to develop objective data to substantiate the productivity and economics of different farming systems (conventional, protected cropping and organic production). This included a range of experiments that were conducted in farmer fields, research fields and as pot culture in protected structures. Nitrogen application is a key input in the intensive conventional systems and N response experiments were conducted in Leyte and Claveria to identify optimal N application rates for the key vegetables (tomato, sweet pepper, eggplant, cabbage and lettuce) in both the wet and dry seasons. In organic production, the key source of nutrients is chicken manure and a pot experiment was completed to optimise the rate of chicken manure application on eggplant and sweet pepper under a protected structure. In response to the national priority to advance organic production a three year experiment was implemented at Bukidnon to evaluate the effects of organic and conventional crop nutrient management in combination with either organic or conventional pest management. This was conducted on sweet pepper, tomato and cabbage as test species. Over three seasons the experiment showed lower crop productivity in organic production particularly with respect to the crop nutrient impact. The details of this are reported in the key results and discussion. A further two field experiments were completed at Claveria and evaluated the interaction between P rate, microbial inoculants and organic fertilisers on cabbage and sweet pepper. Positive response of the inoculant was the ability to achieve greater P uptake (efficiency) at lower P application rates. Demonstration trials have been completed with collaborating farmers in the priority areas of Cabintan (Leyte), Claveria and Bukidnon (Northern Mindanao) and Bohol. In Claveria, the developed best management practice gave a cabbage yield of 24.7 t ha^{-1} compared with the farmer practice of 15.6 t ha^{-1}. Farmer field days have been held in conjunction with these activities. A large number of training activities have been completed (See section 7.3).

2.2	Identify whether differences in food quality exist between organic or conventionally produced vegetables or other factors (eg. Micronutrient limitations) (PC and A)	Conduct assessments of differences in food quality (eg. Vitamin, ascorbic acid shelf life etc.) and report findings.	12/2016	Assessments of food quality differences in vegetables grown under a range of soil management strategies have been completed for pepper (cvs. Emperor and Sultan) and for eggplant (cvs.Morena and Casino). A study on the food quality of sweet pepper grown under conventional and protected cultivation systems has been completed. The measured traits included electrochemical characteristics (electrical conductivity (EC), oxidation reduction potential (ORP), pH and total dissolved solids (TDS)) Free radical scavenging activity (FRSA), Pigment composition (Chlorophylls A and B, total Carotenoids) and Vitamin C concentration. Combinations of mineral fertiliser with chicken manure tended to give the highest concentration of specific analytes particularly for Vitamin C. A particular focus on the effects of chicken manure rate (0-20 t ha^{-1}) showed that FRSA, EC and Vitamin C concentration were highest at about 5-7.5 t ha^{-1} and declined with a further rate increase. Eggplant Cv. Casino had substantially higher FRSA than cv. Morena but lower EC, TDS, chlorophyll A and total carotenoids. Similarly for sweet pepper, significant differences existed between cultivars and fertiliser treatments for some of the measured traits. A series of experiments have been conducted in Australia to evaluate Zn-Biofortification in a high zeaxanthine cultivar and standard cultivar. There was no yield or quality response to Zn application. Further research has focussed on the relationship between the medicinal properties of garlic (allicin content), crop nutrition and genetics.

2.3	Evaluate soil fertility changes over time in organic, conventional and protected cropping production. (PC)	Completion of the protocol for soil monitoring and review by project team and conduct training on protocol. Completion of three seasons monitoring of soil and crop nutrition across production systems and review and report of results. Publishing of a report that compares soil fertility differences between organic nutrient management strategies compared with conventional practice. Presentation of results and extension to farmer groups.	05/2014	A standard protocol was developed for these monitoring experiments conducted over several seasons. This activity defines whether there are objective (measurable) differences in soil fertility between different production systems and assesses what the changes in soil properties in these systems are over time. This provides an assessment of what factors need to be addressed to ensure farming system sustainability. A factorial experiment at Bukidnon Northern Mindanao was set up to evaluate and compare productivity, soil factors and crop health across an organic and conventional production practices. The experiment consisted of a 2 by 2 factorial (4 treatments) including conventional and organic fertiliser practices and conventional and organic pest management practices. The test species were sweet pepper and tomato. A first season comparison of protected and open production of pepper was completed in Leyte on a farmers property and soil and plant analyses completed and compared. In the first season the experiment was negatively impacted by bacterial leaf spot in the test crop sweet pepper. As a recommendation from the mid-project review this activity was reviewed as non-essential. Furthermore, typhoon damage to the protected cropping structure during the second season precluded further research on this activity. In Claveria, two (2) successive trials in 2016 for lettuce were conducted comparing protected and open field production involving two cultivars (leafy and head type) under four N levels (0, 50, 100 and 150 kg/ha).
		Completion of experimentation and reporting to evaluate the efficacy of commercially available organic or biological products on vegetable crop growth.	11/2015	This activity identifies whether the commercially available biological soil additives and foliar sprays contribute to improved crop growth and alleviate soil and nutrition limitations. This activity was reviewed at the Mid-term review and suggested as not being a critical component. Nonetheless a small field experiment was initiated May 2017 to evaluate efficacy of two commercially available organic fertilisers (chicken manure and Well-Grow) and the microbial inoculant (MykoPlus). The bio-inoculant improved P uptake and P use efficiency.
2.4	Evaluate the economics of fertiliser management in organic, conventional and protected cropping production. (PC)	Completion and publishing of an economic analysis of fertiliser impacts on vegetable cropping system productivity.	03/2017	Completed and reported.

Objective 3. To develop improved and targeted site-specific nutrient management strategies

No.	Activity	Outputs/ Milestones	Completion date	Comments
3.1	Experimentation to develop practices for sustainable and balanced nutrient management in vegetable systems. (PC and A).	Complete partial nutrient budgets in various systems (conventional, organic and protected cropping) in the target areas of Bohol, Leyte and Northern Mindanao. Report the partial nutrient budget data and develop guideline nutrient requirements for key vegetables (eg. Tomato, pepper, eggplant and cabbage) and present findings to farmer groups. Identify benchmark nutrient requirements for key vegetables (pepper, tomato, eggplant and cabbage). Completion of field experimentation that identifies optimal major nutrient requirements (eg. N, P and K) for key vegetables (pepper, tomato, eggplant and cabbage). Report the findings of the major nutrient experimentation.	03/2016	The partial nutrient budget protocol was completed and reviewed by the project team and training provided in February 2015. Qld DAF has produced a draft YouTube video clip on how to conduct a nutrient budget. : https://youtu.be/6lKPU6GQIXA A nutrient budgeting activity was conducted in Cabintan Leyte on conventional and protected cultivation systems for sweet pepper. A series of nutrient budgets for tomato crops under protected and open cultivation were completed in Claveria. This activity assisted in identifying the benchmark crop nutrient requirements that maximise yields for farmers and assist farmers and professionals in understanding crop nutrient demand and dynamics. The benchmark nutrient requirements to optimise yield have been identified for eggplant, sweet pepper, tomato and cabbage. Experimentation has evaluated optimal N rates for key vegetable crops including tomato, sweet pepper, eggplant, cabbage and lettuce. The experiment on lettuce at USTP Claveria further evaluated irrigation impacts on productivity. Further pot experiments have evaluated the response of sweet pepper to phosphorus levels in acidic soils. Experimentation in Qld has evaluated optimal N response rates for bunching onion, capsicum and eggplant. This activity has identified the benchmark crop nutrient requirements that maximise yields for farmers and will assist farmers and professionals in understanding crop nutrient demand and dynamics.

3.2	Experimentation to evaluate impact of acid-soil infertility on vegetables completed.	Completion and reporting of soil acidity experimentation including lime response trials in key vegetables.	12/2016	Pot experiments (VSU) have evaluated dolomite at rates of 0-9 tonne ha^{-1} on growth of sweet pepper. Building on this, a field lime experiment was completed in Cabintan (March 2017) comparing dolomite and calcium carbonate at rates of 0-10 tonne ha^{-1} using sweet pepper and tomato as test species. Phosphorus rate trials have been completed in conjunction with lime on sweet pepper at VSU Leyte. The results of these trials have highlighted the significance of soil acidity impacts on vegetable crop growth and allowed the development of cost effective strategies to increase crop productivity for small farmers.
		Completion of bioassay experiments to evaluate the impact of Al toxicity on key vegetable crops.	02/2016	A range of bioassay experiments have been completed. These have been completed in Australia and the Philippines using green bean, capsicum and cabbage as test species. The equipment and training were provided to UPLB in April 2014 and subsequent refinement and training conducted. Researchers at UPLB have completed studies on effects of Al on Philippine sweet pepper cultivars. The development of the technique is a capacity improvement in the Philippines and the assay is functioning and can be extended to other research. Australian research evaluated the relationship between soil acidity constraints, genetics for vegetable tolerance of acidity constraints and relationship with pathogen infection. The research has focussed on two aspects. The first was the effect of acidity and Al on capsicum root system growth that has highlighted root sensitivity to pH values higher than that at which Al is a problem. The second looked at the interaction of pH, Al and soil pathogen (Pythium) infection.

3.3	Experimentation to evaluate impact of micronutrient responses on vegetables. (PC and A)	Completion and reporting of experimentation that identifies vegetable responses to micronutrients.	12/2015	A series of about seven nutrient omission pot experiments on both major and micronutrients have been completed by VSU, UPLB and USTP on a range of soil types including calcareous (Inseptisol) soils and acidic soils (Ultisol, Oxisol and Andisol). Initial experiments were conducted using maize as the diagnostic species with subsequent experiments conducted on sweet pepper, eggplant and cabbage. To assess the micronutrient status of vegetables in the priority areas of Leyte and Northern Mindanao (Claveria and Bukidnon) a survey of cabbage leaf samples was conducted, sampling the youngest wrapper leaf. The survey results are reported in detail in section 7. A field trial was completed by VSU (Cabintan Leyte) to evaluate the response of sweet peppers to foliar micronutrient application (zinc, boron and molybdenum). A further ongoing experiment at VSU has evaluated the various effects of a range of nutrient practices, including application of Zn, B and Mo on growth and yield of eggplant and pepper. Experiments in Australia have been completed that evaluate Zn, B, Cu and Mo effects on garlic and capsicum (sweet pepper). Some of this focus was associated with the negative effects of different N forms on plant growth identified in Qld vegetable production systems. Further research in Australia has evaluated the uptake of Zn in sweetcorn and opportunities for sweetcorn kernel biofortification with Zn. Several papers have been published from this research and the research has incorporated studies using XAS and XRF at the Australian Synchrotron.
3.4	Evaluation of organic matter mineralisation to assess N release (mineralisation)	Completion of trials and development of tools/data to better understand N mineralisation	03/2017	This activity evaluated the release rate of N from organic amendments which can then be used to quantify the contribution from these sources to crop N nutrition. A series of two incubation experiments (UPLB) were completed that determined the C and N mineralization rates for different organic materials in acidic soils.

3.5	Develop and extend knowledge of improved vegetable crop nutrient practices.	Demonstration trials conducted with stakeholder farmers and agricultural professionals and advisers. Guidelines for improved nutrient management developed and extended to regional/municipal agricultural extension officers.	12/2016	A large number of demonstration trials along with training workshops have been conducted in Claveria (USTP), Bukidnon (BSWM), Cabintan (VSU) and Bohol Island (LFPI) on both acidic and calcareous soils. In Australia, vegetable farmers were invited to evaluate trials on bunching onion N nutrition and garlic farmers to evaluate garlic nutrition response trials. Formal garlic productivity field days and forums have been held in Queensland (2015, 2016 and 2017) and attended by about 120 garlic growers. A large number (~40 visits) of *ad hoc* individual visits were made to field trials by farmer and industry members. Bunching onion growers from the Lockyer Valley attended a nutrient management field day in August 2016. Guidelines for improved soil and nutrient management have been developed and used to provide training directly to farmers and to extension staff and Municipal Agricultural officers that will allow the information to be adopted more widely. Considerable farmer training has been conducted including • 75 participants attended training at Lantapan Bukidnon (June 27-28 2017). • 70 participants attended training in Davao (Nov 8-9 2017). • 60 participants attended training in Impasugong Bukidnon (May 22-23 2018). • 80 participants attended training at USTP Claveria (May 24-25 2018). • Dr Apol conducted a Radio talkback on USTP radio station in November 2017 to discuss the project findings. • Farmer field day conducted at USTP Claveria Nov 2017. • 209 people attended the USTP farmer field day event in Claveria Dec 13-14 2017.

Objective 4: Assess the interaction between vegetable genetics and soil and nutrient limitations

No.	Activity	Outputs/ Milestones	Completion date	Comments
4.1	Develop nutrient response profiles for crop species and cultivars. (PC and A)	Completion of experiments on nutrient responses in crop species/cultivars and reporting. Produce knowledge and recommendations for nutrient management for specific vegetable cultivars.	04/2017	The experiments conducted under objectives 2 and 3 evaluated the effects of nutrient management programs, including nutrient rates, micronutrient and liming on multiple cultivars. Soil and nutrient response trials (N, P and chicken manure) have been completed for tomato (Harabas and AVTO 1173), eggplant (Casino and Morena), lettuce (head and leafy type) and cabbage (KEX-734 and Resist Crown) in wet and dry seasons. In Australia, nutrient response profiles were developed for 2 cultivars of bunching onion (Paragon and Zoolander) and capsicum (Warlock and Plato) along with grafted lines of Plato and Warlock over elite root system accessions (42-2, 42-3 etc). Mineral nutrition profiles have been developed for a suite of 30 garlic varieties. Information is available for specific recommendations on vegetable cultivars and the information has been presented to farmers at a large range of training workshops.
4.2	Evaluate and identify the sensitivity of vegetable crop species and cultivars to soil-acidity limitations (Al toxicity).	Completion of report on experimentation and recommendations developed for germplasm adaptability.	12/2018	This objective directly links to Objective 3.2. A series of solution culture experiments have been initiated in the Philippines and Australia to evaluate the effects of pH and Al on bean, capsicum and cabbage. The preliminary studies were conducted on the large seeded vegetable green bean to ensure the system was functioning well. The system was subsequently fine-tuned for small seeded species including capsicum (pepper) and cabbage. The experiments showed capsicum was sensitive to reductions in pH from 5.5 to 4.8 as opposed to Al toxicity that occurs at pH 4.5. An experiment was completed to evaluate the differential effects of pH (4.2, 4.5, 4.8, 5.1, 5.6). Further research in Australia evaluated the interaction between pH, Al and pathogen infection (the non-obligate pathogen *Pythium*). Key findings identify that the pathogen pythium has capacity to alkalise growth media (PDA and V8 growth media) raising pH from an initial 4.0 to about 6 over a period of about 7 days. Further research suggests Al suppresses pythium development.

4.3	Identify improved pepper genetics adapted to low soil fertility (including aluminium toxicity and high nutrient acquisition rates). (PC and A)	Complete screening of pepper and eggplant germplasm for tolerance to Al. Reporting on the identification of accessions of pepper and eggplant with tolerance to Al toxicity.	12/2016	These improved genetics offer the potential to greatly reduce fertiliser and ameliorant application rates increasing farmer profits. Three experiments have been completed by Qld DAF that evaluated grafted commercial varieties over rootstocks of wild *Capsicum chinense*. The experiments have included solution culture, glasshouse and field experiments. These results have identified several cultivars with root systems that confer higher productivity and include Qld DAF lines 42-3, 45-1, 71-3-1 and 71-3-3. Of particular interest is that the high performing line 45-1 (Qld DAF nomenclature) is from the USDA collection (PI 281417 01 SD) and originated in the Philippines, collected in 1962.

Objective 5. To deliver training and extension to advance soil and nutrient management skills in extension and research staff

No.	Activity	Outputs/ Milestones	Completion date	Comments
5.1	Conduct training in Philippines and Australia to improve research capacity and knowledge.	Specific training materials and modules developed for vegetable professionals (including experimental design and analysis and soil and plant sampling and analysis).	12/2016	In the Philippines, a large range of training activities have been conducted and are documented in detail under Section 8 - Impacts. This includes statistical training, writing workshops, field excursions visiting scientist presentations and specific skills training. Under the project, a large number of students have completed undergraduate and postgraduate study programs. In Australia, four postgraduate students (2 PhD and 2 masters) are conducting studies under the project.
5.2	Complete demonstration trials and field days, publish information and conduct training for nutrient management by smallholder vegetable farmers. (PC)	Training materials developed and farmer field schools and at least 2 train the trainer workshops held.	12/2016	A large number of demonstration trials and field days have been completed (see objectives 2 and 3 above) and details of these are included in section 8.4.
5.3	Philippine project members visit Australia for science methodology and technology training (PC)	Training in Australia completed and reported by the touring group.	10/2015	A visit to Australia was made by 10 members of the Philippine project team representing 4 of the collaborating groups and included training and vegetable system field tours from 17 to 30 April 2016.

7 Key results and discussion

7.1 Soil fertility constraints to vegetable productivity

Survey identification of vegetable soil and crop nutrition constraints.

General findings

The majority of vegetable farms surveyed in Claveria, Leyte and Bohol were small-scale eggplant farms found across upland, hilly and lowland areas. The soils vary from young Inceptisols to relatively old Ultisols, developed from various kinds of parent material (Table 7.1). In Bohol, limestone is the most common parent rock, while in Claveria it is mainly volcanic parent rocks. In Leyte, soil type was more varied consisting of volcanic and alluvial sediments as the dominant parent rocks for soils in the upland and lowland areas. Cabintan is the major vegetable production area of Leyte and located in the central highlands where the predominant soils are geologically young Andisols formed from volcanic deposition. The soils in vegetable farms in Samar are mostly derived from mudstone; the dominant parent rock on the island. These fundamental differences in soil type greatly impact on fertility management strategies for vegetable production.

Vegetable production is widespread across Claveria and Leyte whilst in Samar vegetable production is not a common livelihood; probably due to the prevalence of mudstone soils with low fertility. Across vegetable farms the majority of farmers were male and married (Fig. 7.1) and age varied from less than 35 to more than 60 with a large number in the 50-55 year age group.

Table 7.1. Parent materials of soils planted to vegetables surveyed

Place	Parent material	Dominant soils
Bohol	1. Limestone 2. Alluvial Sediments 3. Mudstone	Young soils (Entisols, Inceptisols)
Misamis Oriental	1. Volcanic Rocks	Old soils (Ultisols, Oxisols)
Leyte	1. Volcanic Rocks 2. Alluvial Sediments 3. Limestone	Old & young soils (Ultisols, Andisols, Inceptisols, Entisols)
Samar	1. Mudstone 2. Alluvial Sediments	Mature and young soils (Alfisols, Inceptisols)

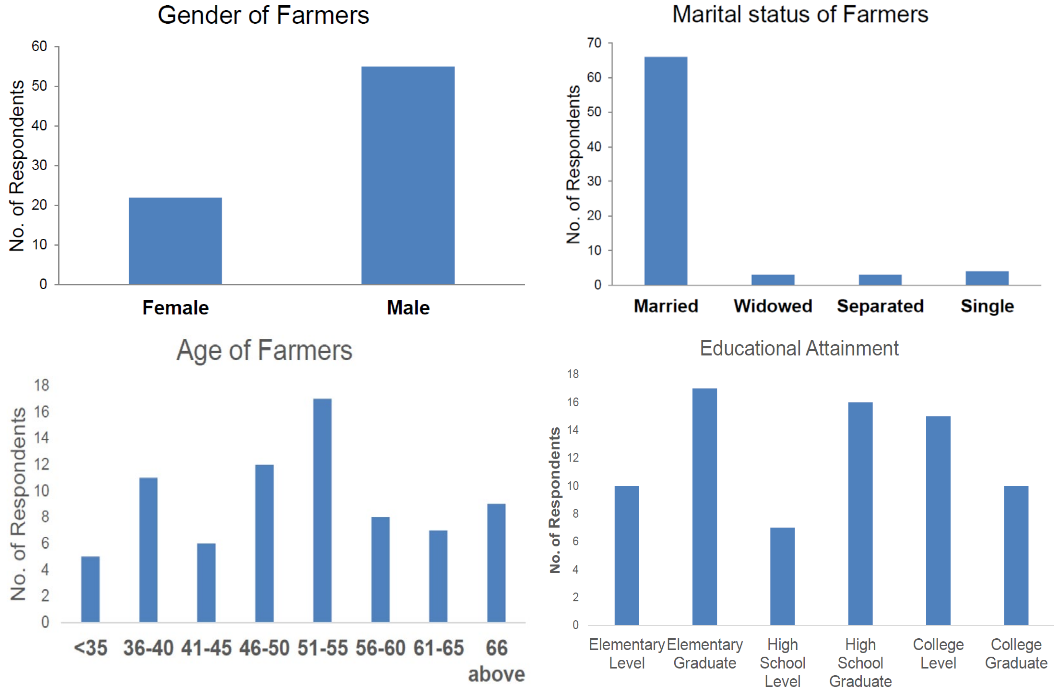


Figure 7.1. Characteristics of vegetable farmers interviewed

The survey revealed that the majority of the vegetable farmers prepare their soil manually with hand tools and a large number also use Carabao-drawn implements (plough and harrow) and a few large-scale farms used tractors. Eggplant (cvs. Morena and Casino) was the dominant vegetable crop followed by sweet pepper (cvs. Emperor and Sultan). Plant spacing varied greatly from farmer to farmer giving a highly variable plant population and yield. Land was predominantly owned by farmers but a substantial number of farmers rented or leased land (Fig. 7.2). Irrigation is commonly practiced for vegetable production and water is obtained from many different sources though the dominant sources include river water, domestic water supply systems and ground water (water pumps and deep wells) (Fig. 7.2).

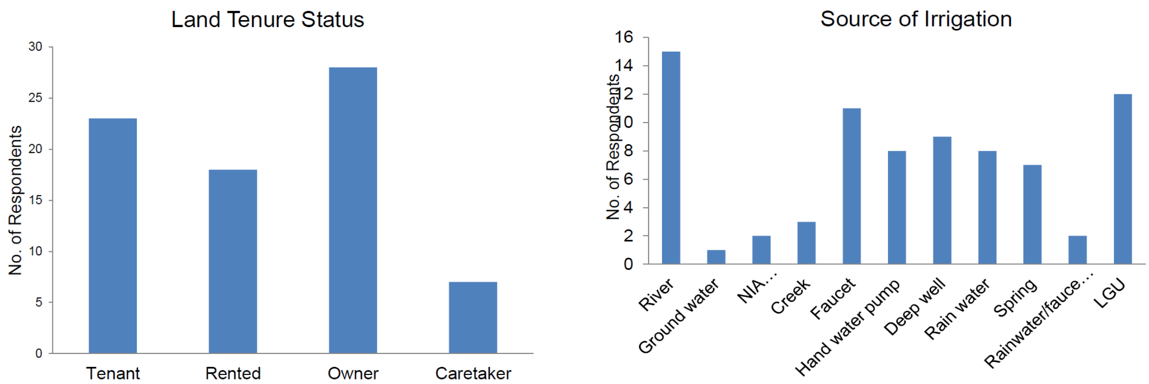


Figure 7.2. Land tenure status and source of irrigation of vegetable farms

Most farmer respondents identified soil fertility as a major problem affecting their vegetable production. This was based on their experience and knowledge of the visual appearance of their crops (crop health) and their soil. Consequently, they apply many kinds of organic and chemical fertilisers. The main organic fertilisers include animal manures and chicken manure, and mineral fertilisers mainly include urea and "Complete". Application rates of fertiliser varied greatly from farmer to farmer. Most respondents used farmer to farmer communication, extensionists and personal experience as the basis for determining the appropriate rate of fertiliser. An observation in the field survey assessments was that poor fertiliser application technique was common (Fig. 7.3) and over application of fertiliser was common resulting in high production costs and environmental pollution.

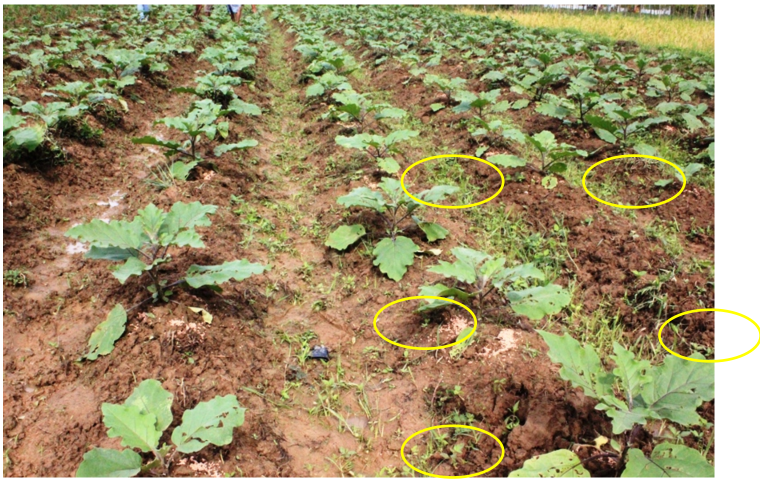


Figure 7.3. Example of incorrect fertiliser application by vegetable farmers

Soil and plant survey

Soil pH values across and within the surveyed areas varied considerably (Fig. 7.4), however, at individual sites there was only a relatively small difference in pH values between the 0-20 cm and 20-40 cm samples. At sites where alkaline soils predominated the subsoil pH tended to be higher than the surface soils whereas at acidic sites (eg. Claveria) subsoil pH was substantially lower than that in the surface soil (Fig. 7.4). The differential between surface and subsoil pH is presumably related to the higher soil organic matter in the surface soil samples, and the surface application of lime on acid soils.

Across samples collected from Bohol, Leyte, Samar and Davao there was a wide distribution of pH values from strongly acidic samples (pH≈4) through to moderately alkaline (pH≈8.2). Across these sites about 40-60% of soil samples were in a pH range of 5.5 to 7.0 considered optimal for most crops, including vegetables (Landon, 1991; Hazelton and Murphy, 2007). The survey results across Bohol, Leyte, Samar and Davao showed that approximately 50% of sampled sites had pH values outside of the optimal range, being either below (too acidic) or above (too alkaline) that identified for optimal vegetable crop production. The soil samples from Bohol, Leyte, Samar and Davao were strongly represented by calcareous soils associated with uplifted limestone deposits resulting in mildly alkaline pH values (≈8.2).

In contrast to the other four regions, about 65% of the surface-soil samples and 75% of the sub-soil samples from Claveria had pH values less than 5.5 (Fig. 7.4). Furthermore, the box-plot quartiles for the Claveria samples were compressed indicating a relatively narrow and consistent range of pH data reflecting the uniform soil type used for vegetable production in Claveria. Claveria is one of the most significant vegetable production areas of the Philippines, where a combination of fertile, but acidic, volcanic soils and upland climate strongly favour the production of vegetables. Soil acidity constraints remain a key vegetable productivity limitation on soils in Claveria. The data indicates that, despite the intensive nature of vegetable production and the regular incorporation of lime and manure, soil acidity is likely to still be a constraint to production, and liming rates are generally not sufficient to optimise vegetable crop productivity.

In Leyte, there was a high proportion of soils (≈75%) for which pH was greater than 5.5 and about 20% of samples were in excess of 7.0. The data for Leyte showed a considerable spread across the 4 quartiles and indicated high variability in soil type across the island. Like Claveria, the district of Cabintan (Leyte) is one of the most significant vegetable production areas of the southern Philippines and also having a combination of acidic upland soils and climate that make it highly suited to vegetable production. To evaluate the potential pH constraints to vegetable production in Cabintan, the data for Leyte was broken down into data for Cabintan and the rest of Leyte (Leyte–Other) that includes alkaline and acidic sites, and compared with the acidic soils of Claveria (Fig. 7.4). Soil acidity constraints were a major problem in Cabintan where about 60% of samples were below the lower optimum of pH 5.5 and about 20% of samples were strongly acidic (pH<5.0). The upper two quartiles for the soil pH distribution were similar between surface-soil samples from Cabintan and Claveria where about 40% of samples were above 5.5. However, for the lower two quartiles and for the subsoil samples the Claveria sites were more strongly acidic than the Cabintan soils. The pH of the Cabintan soils was strongly differentiated from that of other parts of Leyte reflecting the high regional variability in soil type. Indeed, the 25-100% quartiles for pH at Leyte-Other (pH about 6.2-8.2) sat above the 0-100% quartiles for both Claveria and Cabintan (pH about 4.2 to 6). Though both areas have volcanic derived soils, the soils in Cabintan are represented predominantly by young volcanic Andisols whereas Claveria is dominated by older more weathered Ultisols.

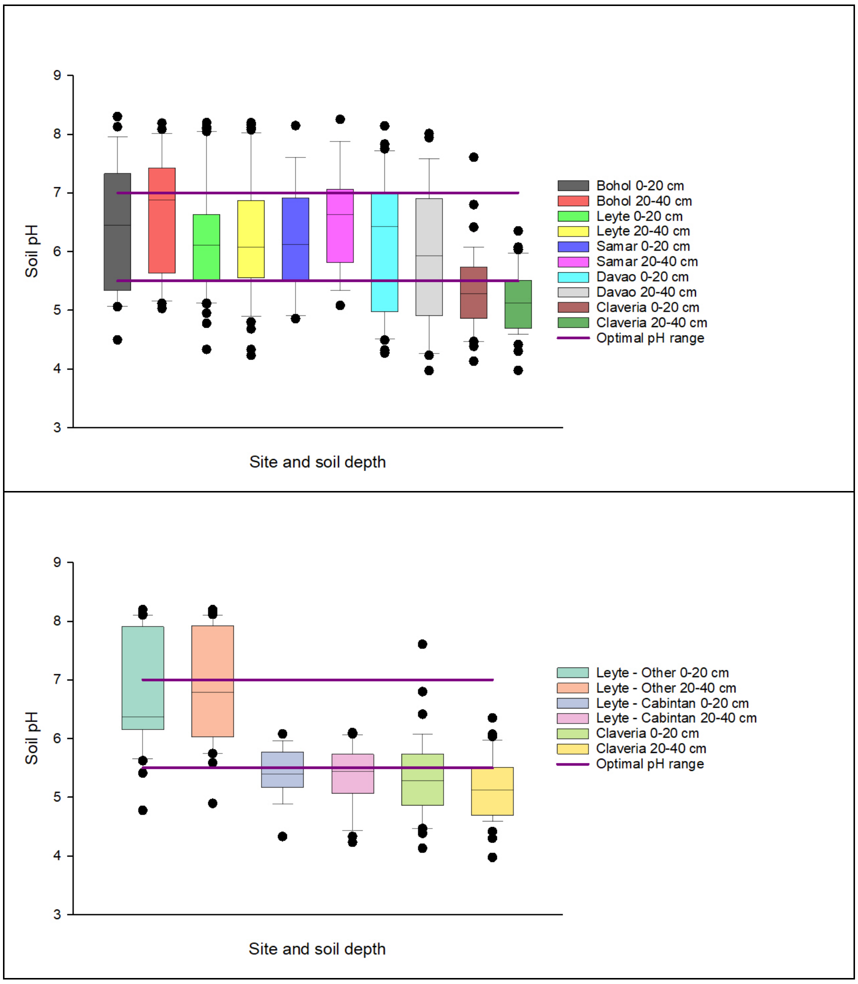


Figure 7.4. Box-plot graphs of distribution of pH values of soils sampled across vegetable production areas of the southern Philippines (top graph) and a comparison of samples from acidic sites (Cabintan – Leyte and Claveria) and other sites from Leyte (Lower).

Across all sites there was a high proportion of soil samples where the P status was below an identified sufficiency threshold (14 mg kg^{-1}). This was particularly so for Bohol, Samar, Davao and Claveria where more than 50% of surface soil samples were below 14 mg kg^{-1} and for Leyte about 25% (Fig. 7.5). The soils collected from Claveria had very low P status consistent with expectations of acidic upland soils where P fixation reactions regulate P availability. This is despite the widespread and large application rates of P fertilisers. For Claveria, about 85% of the interquartile range for P in surface soils was below 14 mg kg^{-1} and 100% of the subsoil samples. A similar pattern was observed for soils from Samar where almost 75% of the interquartile range was below 14 mg kg^{-1} but with a wider spread of values than was observed for Claveria. Despite the similarities in box-plot distributions for P concentration between Claveria and Samar the mechanism for low P status was fundamentally different. The Samar area is predominantly low fertility (low P) soils originating from mudstone whilst Claveria soils are predominated by P fixation reactions associated with acidic soil sesquioxides. In Claveria, the uniformity of soils gave a more limited variability but consistently low range of P concentrations.

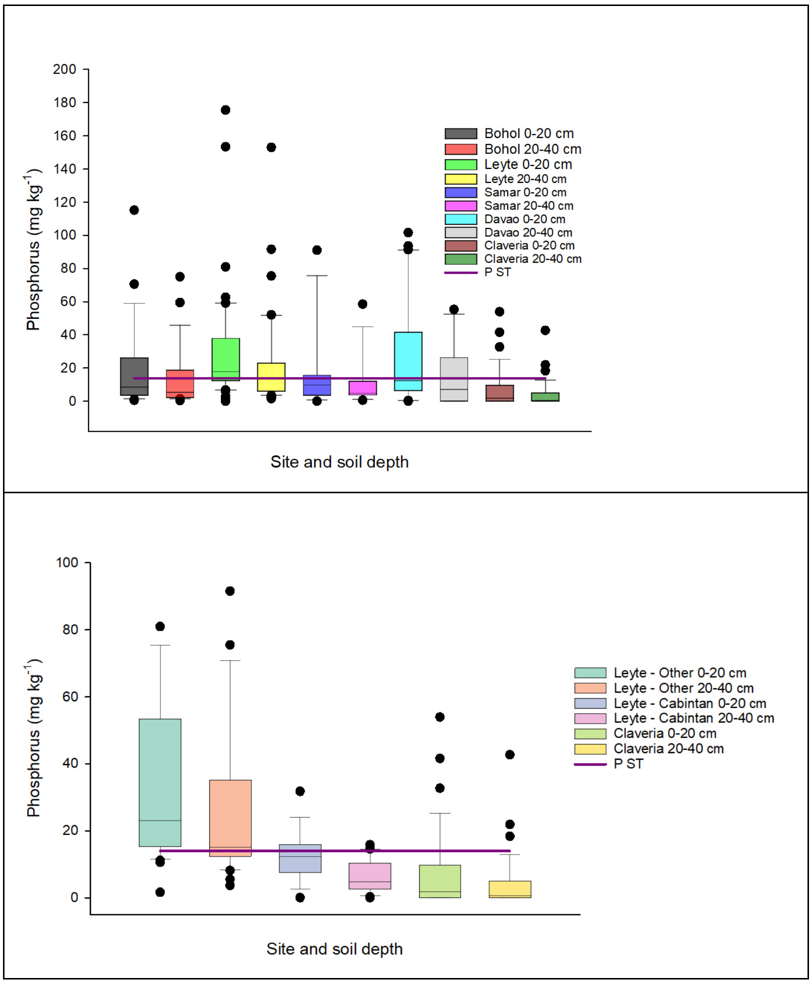


Figure 7.5. Box-plot distribution of P concentrations in soils sampled across vegetable production areas of the southern Philippines (top graph) and a comparison of samples from acidic sites (Cabintan – Leyte and Claveria) and other sites from Leyte (Lower).

As for the pH data, the range of P concentrations in Leyte soils was large (from 0.05 to 180 mg kg^{-1}). A break up of the data into the acidic soils from Cabintan and other Leyte soils also highlighted a similar response to that for pH (Fig. 7.5). About 75% of the interquartile range for the other Leyte sites had sufficient P but in the acidic Cabintan soils about 70% of the interquartile range was below a sufficiency threshold of 14 mg kg^{-1}. The distribution of P concentrations was similar between Claveria and Cabintan though Claveria soils tended to be of lower P status which is consistent with it also having lower pH and being more weathered. Hence, despite the volume of knowledge about P limitations in acidic soils, low P status appears to remain a problem on intensively managed acidic vegetable soils in the Philippines.

At all sites the Ca status of soils was above a sufficiency threshold of about 2 meq $100g^{-1}$; though the soil Ca levels for Leyte were considerably higher than at other sites, ranging from about 3 to 180 meq $100g^{-1}$ in the surface soil. Importantly, the Leyte data does not include samples from the acidic soils at Cabintan, for which analysis was not completed. Though the Ca status for Claveria soil samples was sufficient (>2.0 meq $100g^{-1}$) the soil Mg levels were below an adequacy threshold of 0.5. meq $100g^{-1}$ (Fig. 7.6). Lime application is routinely practiced in Claveria and presumably the lime sources are predominantly Ca based and not dolomitic.

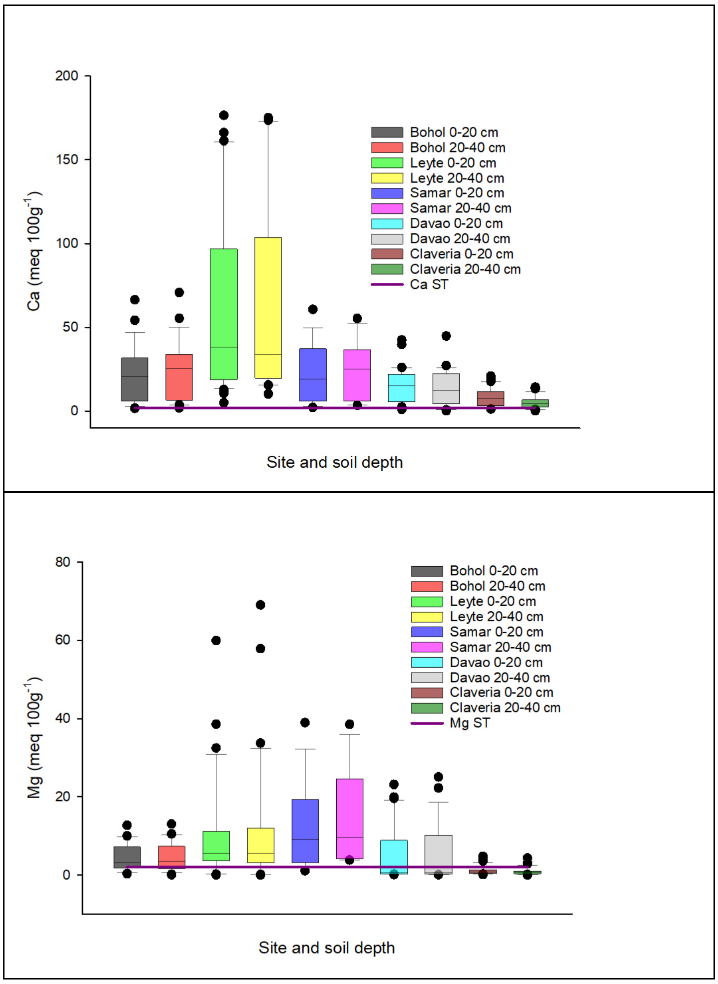


Figure 7.6. Box-plot distribution of Ca and Mg concentrations in soils sampled across vegetable production areas of the southern Philippines.

The distribution of data for soil total N was variable within sites but relatively consistent across all sites and soil depths (Fig. 7.7) suggesting soil N is not directly related to inherent soil properties. The soils in Claveria had a narrower range of N values across the interquartile range despite high N application rates, as mineral fertiliser and chicken manure. In contrast to soil N, soil organic matter (SOM) varied considerably from location to location but Bohol generally had lower SOM values compared with other sites. For Samar, Davao and Claveria, SOM tended to be considerably higher, where more than 75% of samples had SOM values greater than 1.7%; a level considered moderate for vegetable production (Hazelton and Murphy 2007).

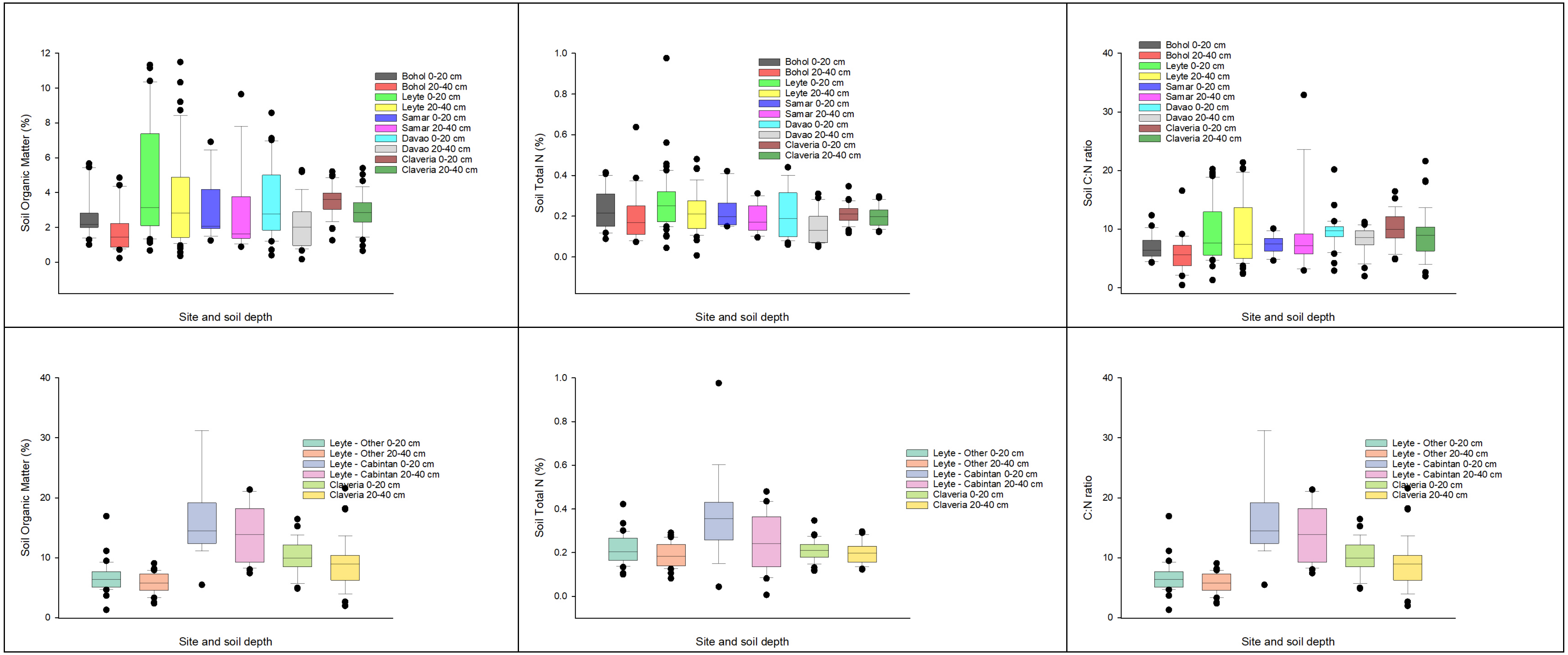


Figure 7.7. Box-plot distribution of soil organic matter, soil total N and soil C:N ratio in soils sampled across vegetable production areas of the southern Philippines (top graph series) and a comparison of samples from acidic sites (Cabintan – Leyte and Claveria) and other sites from Leyte (Lower graph series).

For SOM in soils collected from Bohol, Samar, Leyte and Davao the range in the first and second quartiles was relatively compressed while the third and fourth upper quartiles had a wider range indicating large variability in SOM values (Fig. 7.7). The median SOM values for both the 0-20 and 20-40 cm samples at Claveria were greater than that of the other sites and all quartiles for Claveria were compressed indicating a greater consistency in values compared with other sites. This probably reflected a more consistent soil type and farming dynamic (principally vegetable farming). A breakdown of the Leyte soils into the Cabintan soils and others Leyte soils showed very high SOM values in the Cabintan soils. Indeed 100% of the quartiles were above that for the upper quartile for Claveria and other Leyte sites (Fig. 7.7). The soils in Cabintan consist of fertile young volcanic soils with inherently high organic matter. The widespread application of organic fertilisers likely contributes to the relatively high organic matter status in soils used for intensive vegetable production.

Soil samples from all sites, except Cabintan, were analysed for the micronutrients Fe, Zn, Mn and Cu but not for B or Mo, which are not easily or routinely analysed in the Philippines. The status of Fe, Mn, Zn and Cu was generally above the sufficiency threshold in both surface and subsoil samples (Fig. 7.8). Greater than 90% of the samples from the interquartile range were above the sufficiency threshold for Fe, Mn and Cu, while for Zn the value was about 75%. For Claveria, the soils had considerably higher concentrations of Mn, Zn and Cu than other sites. About 75% of samples from Claveria were above a critical upper limit for Mn (45 mg kg^{-1}) and more than 25% of the samples were above a threshold where Cu toxicity is a concern (10 mg kg^{-1}). The excessive accumulation of Mn, Zn and Cu, particularly in Claveria, is likely due to the high application rates of chicken manure and crop protection products in intensively managed vegetable production.

Common fungicides and bactericides have Mn, Zn or Cu as active components. Given that Mn and particularly Cu are at very high concentrations in Claveria soils and these soils are strongly acidic there is a reasonable expectation that both Mn and Cu toxicity may limit vegetable crop growth. Though data was not collected it is likely that excessive levels of Mn, Zn and Cu would be an issue at Cabintan since it is also an intensive vegetable production district. Survey work on chicken manure usage has shown that the application of minerals from chicken manure is substantial (Table 7.2) in the intensive vegetable production regions of Claveria and Cabintan. At an average annual application rate of 10 t ha^{-1} chicken manure, acknowledging farm-to-farm variability, application rates of Zn are three times removal while Cu application (2.4 kg ha^{-1}) is 8 times removal. Furthermore, the application of Zn and particularly Cu as crop protectants is substantial. A single spray of $Cu(OH)_2$ applies 0.6 kg Cu ha^{-1} and about 10 sprays per season are applied in specific vegetable crops. Hence the net application rate per season is about 6 kg ha^{-1}. The combined seasonal application rate of Cu as chicken manure and bactericide is about 8-9 kg ha^{-1} and approximately 30 times crop removal. There is potential for Cu to accumulate in soil at concentrations toxic to vegetable crops, particularly on the acidic soils where Cu availability is high. This represents a serious problem for long-term viability and sustainability of vegetable production on Philippine acidic upland soils.

To complement the soil survey, plant tissue samples were collected across a range of vegetable crops but mostly from eggplant, tomato and sweet pepper. More than 75% of samples at all sites had N concentrations above a general sufficiency threshold of 3.5% (Weir and Cresswell 1993) and 100% of samples had sufficient N on a generic critical N concentration basis of >2% (Marschner, 1995) (Fig. 7.9). Similarly, almost 100% of samples had P status above a threshold of 0.3% (Marschner, 1995) (Fig. 7.9). In contrast to this result, the available P for most soils was below the adequacy threshold of 14 mg kg^{-1} (Landon, 1991) (Fig. 7.5). This anomaly is likely due to the disparity between the soil collection (sampling) process and vegetable grower P fertiliser application technique. Bulked soil samples are analysed for P, whilst P fertiliser is banded close to the plant root zone that reduces the effective fixation of P allowing improved plant P uptake. In contrast to N and P, more than 75% of samples had a tissue K status below a sufficiency threshold of 3.5% (Fig. 7.9) and this was despite the fact that the soil exchangeable K (Fig. 7.10) for most of the soils (>95%) was above a sufficiency threshold value of 0.2

meq/100g (Landon, 1991). This indicates a mismatch in sufficiency criteria between soil and plant testing.

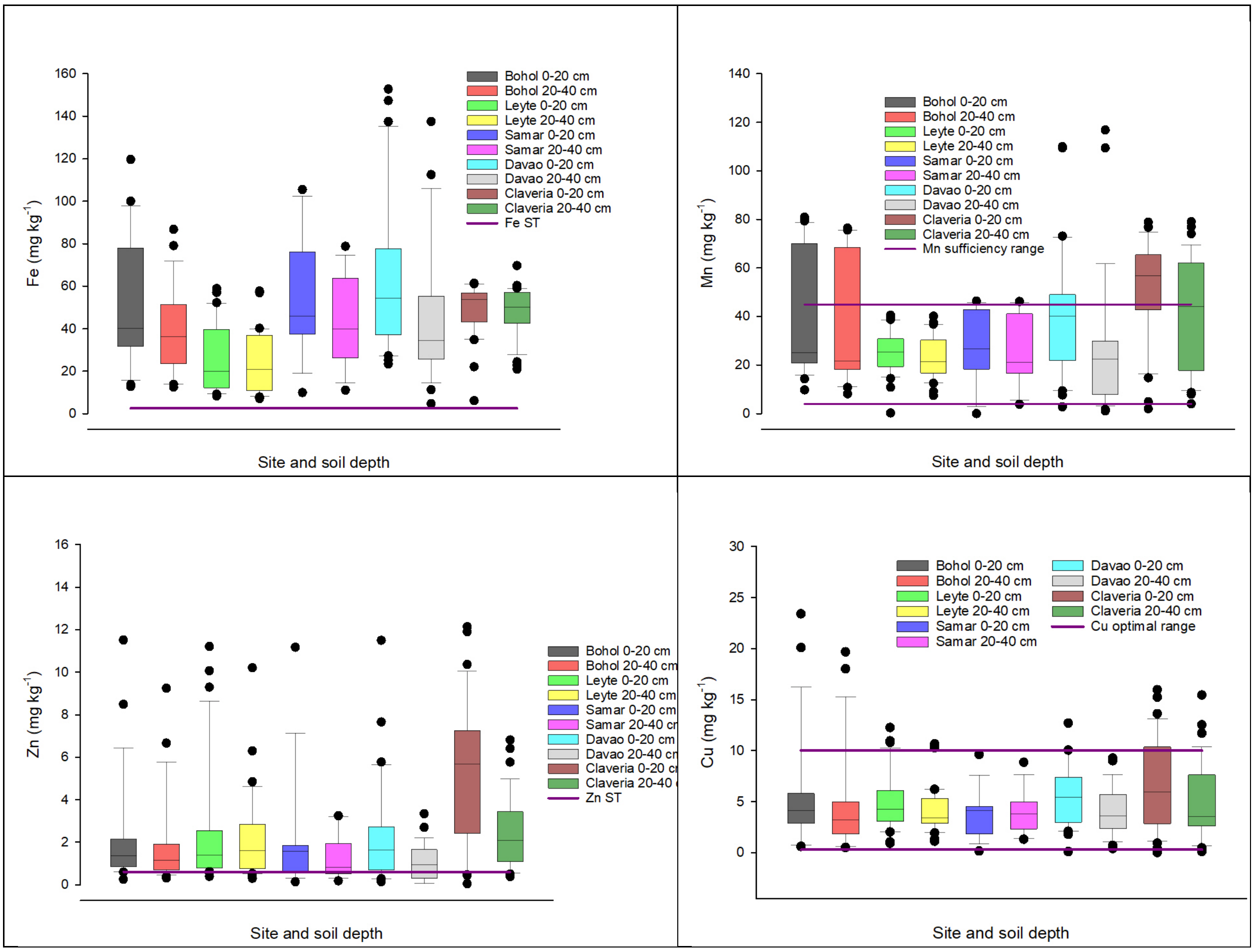


Figure 7.8. Box-plot distribution of Fe, Mn, Zn and Cu concentrations in soils sampled across vegetable production areas of the southern Philippines.

Table 7.2. Average nutrient (element) analysis for chicken manure, nutrient application rate (based on 10 t ha^{-1}) and typical element removal rates for vegetables in the Philippines.

Element	Element Concentration	Element application (kg ha^{-1})	Estimated crop removal (kg ha^{-1})
Nitrogen	3.24 (%)	285	248
Phosphorus	8.26 (%)	727	35
Potassium	4.19 (%)	369	225
Calcium	2.16 (%)	190	114
Iron	620 (mg kg^{-1})	7.7	20
Magnesium	687 (mg kg^{-1})	5.5	17
Manganese	875 (mg kg^{-1})	2.8	7.0
Copper	272 (mg kg^{-1})	2.4	0.3
Zinc	272 (mg kg^{-1})	6.0	2.0

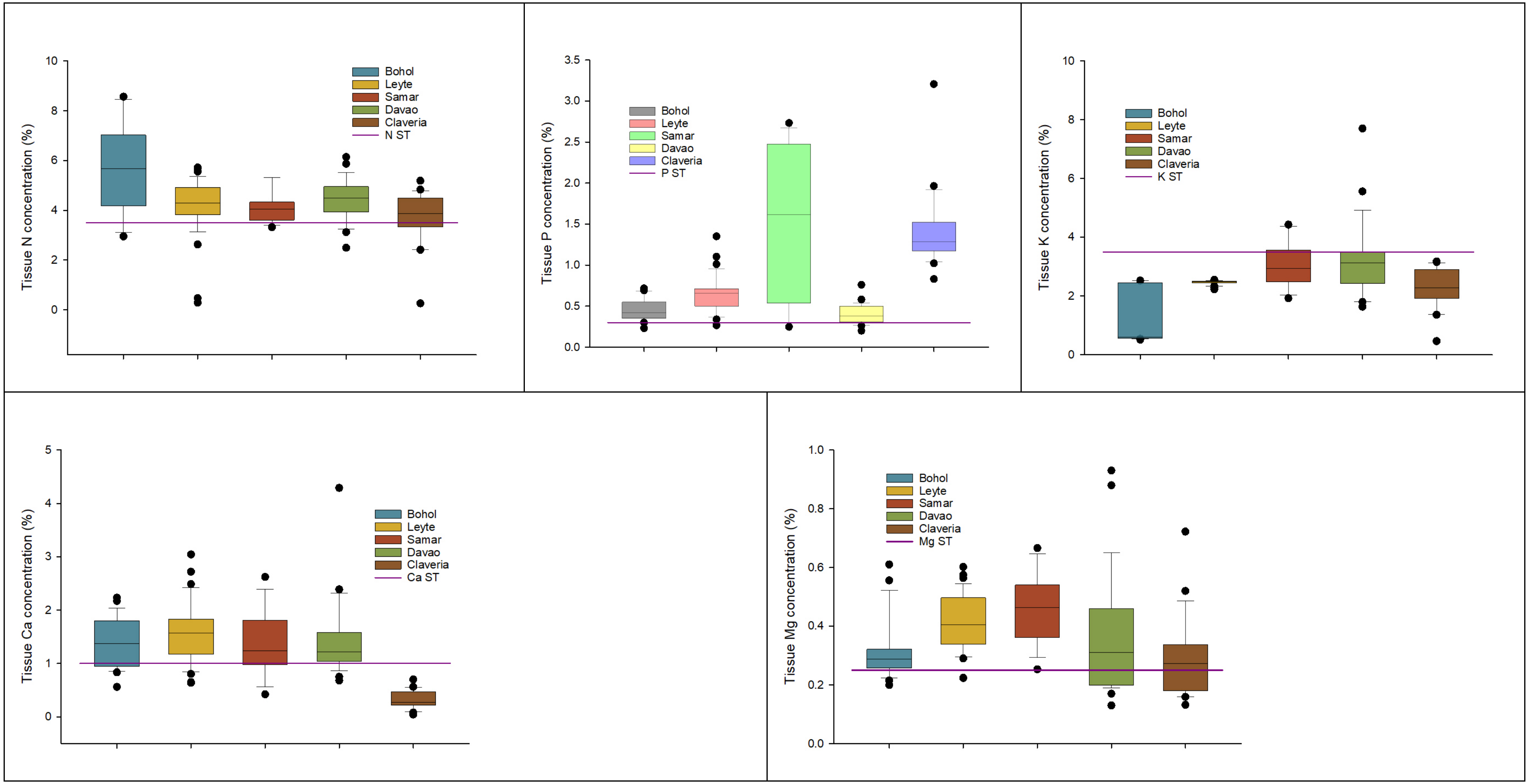


Figure 7.9. Box-plot distributions of N, P, K, Ca, and Mg concentrations in vegetable plant tissue sampled across vegetable production areas of the southern Philippines.

With the exception of Claveria, more than 75% of samples from all regions had tissue Ca concentrations above a threshold of about 1.0% for solanaceous species (Reuter and Robinson 1997). All samples collected from Claveria were below the 1% threshold and was in contrast to the Claveria soil data that indicated more than 75% of samples were adequate for Ca. The majority of samples (>75%) from Bohol, Leyte (excluding Cabintan) and Samar had tissue Mg concentrations above a sufficiency threshold of 0.25%. About 50% of tissue samples from Claveria had Mg concentrations below a sufficiency threshold of 0.25%, a result consistent with the soil data where 100% of samples were below a sufficiency threshold.

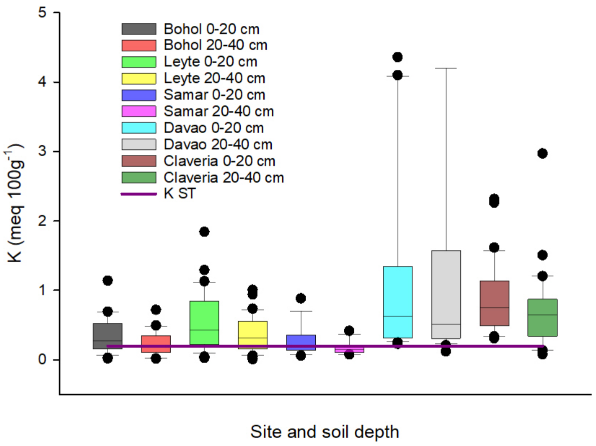


Figure 7.10. Box-plot distribution of K concentrations in soils sampled across vegetable production areas of the southern Philippines.

The majority of tissue samples (~>90%) had concentrations of Fe, Mn and Cu above the sufficiency threshold (Fig. 7.11). The tissue Mn concentration in plant samples from Claveria was very high, where the Mn concentration in more than 50% of samples was greater than 200 mg kg^{-1}. This in combination with very low soil pH values and low soil concentrations of P, Ca and Mg highlight the profound impact of soil acidity constraints in upland acidic soils critical for Philippine vegetable production. The concentrations of Cu in plant tissue were exceptionally high at all sites (75-100% quartiles) and in a range considered toxic. However, an unknown proportion of the measured Cu will be resident on the leaf surface as undissolved $Cu(OH)_2$ bactericide and not strictly contributing to a biological toxicity effect. However, though the exact status of Cu on crop growth at this stage is not definitively resolved, the evidence of high soil Cu concentrations (median 6 mg kg^{-1}) and continued excessive Cu application as bactericide and chicken manure will certainly present problems to vegetable cropping in the future. Improved strategies to manage bacterial pathogens and reduce chicken manure inputs are required to avoid excessive accumulation of Cu.

Data for the tissue mineral concentrations for key vegetables (eggplant, sweet pepper, and tomato) are presented in Table 7.3. The mineral status of leaf tissues across all the samples collected highlighted that N, P, Ca, Fe, and Cu, were sufficient to high in more than 95% of samples (Table 7.3).

In the Philippines the effective capacity to analyse for B and Mo in soils and plant tissue is not developed. These elements almost certainly impact on vegetable crop productivity and require further research.

Across all mineral elements there was a weak positive correlation between soil mineral concentrations and plant tissue concentration (Fig. 7.12 data presented for Ca and Mg only).

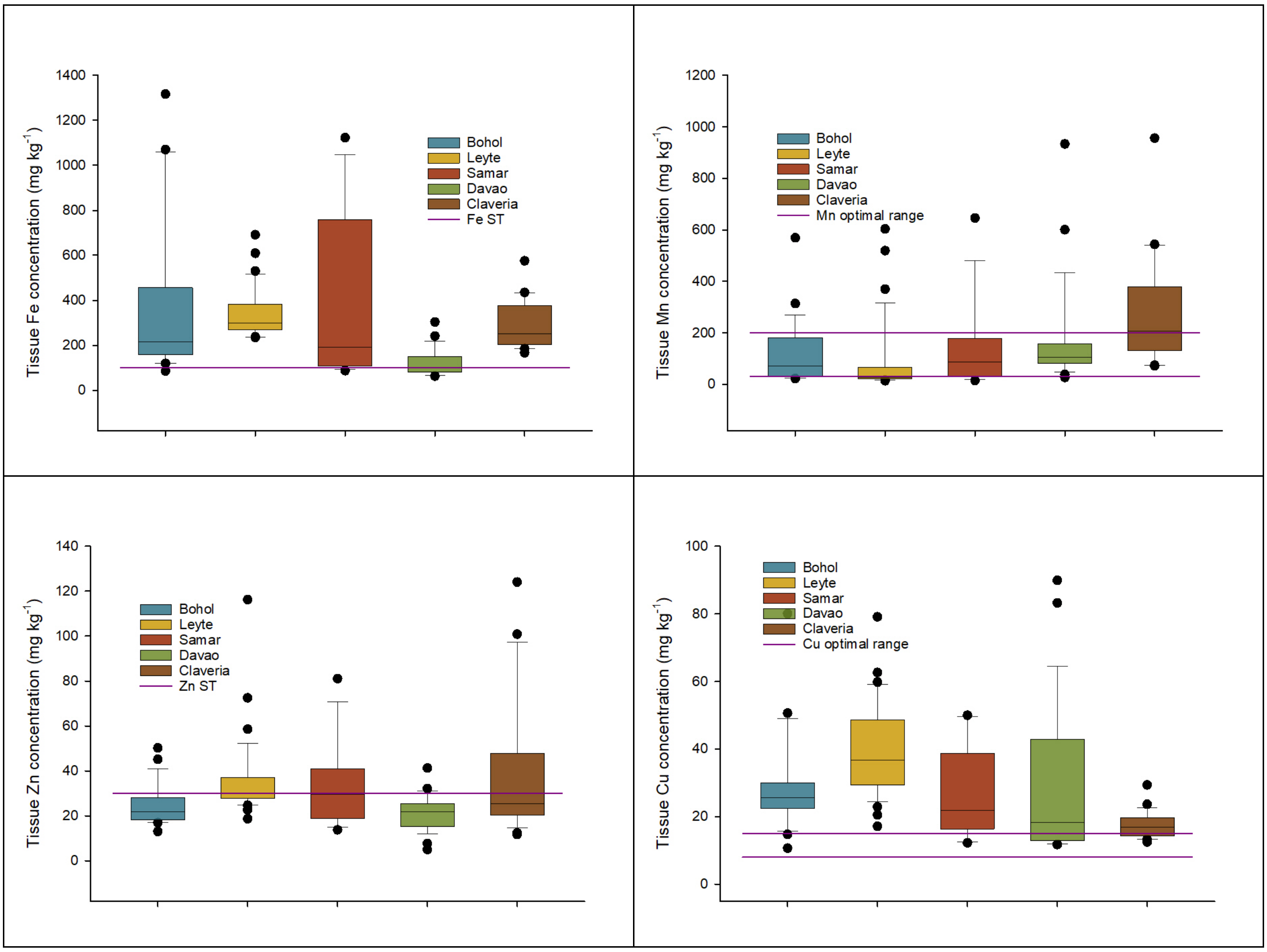


Figure 7.11. Box-plot distribution of vegetable plant tissue concentrations of Fe, Mn, Zn and Cu in samples collected from vegetable production areas of the southern Philippines.

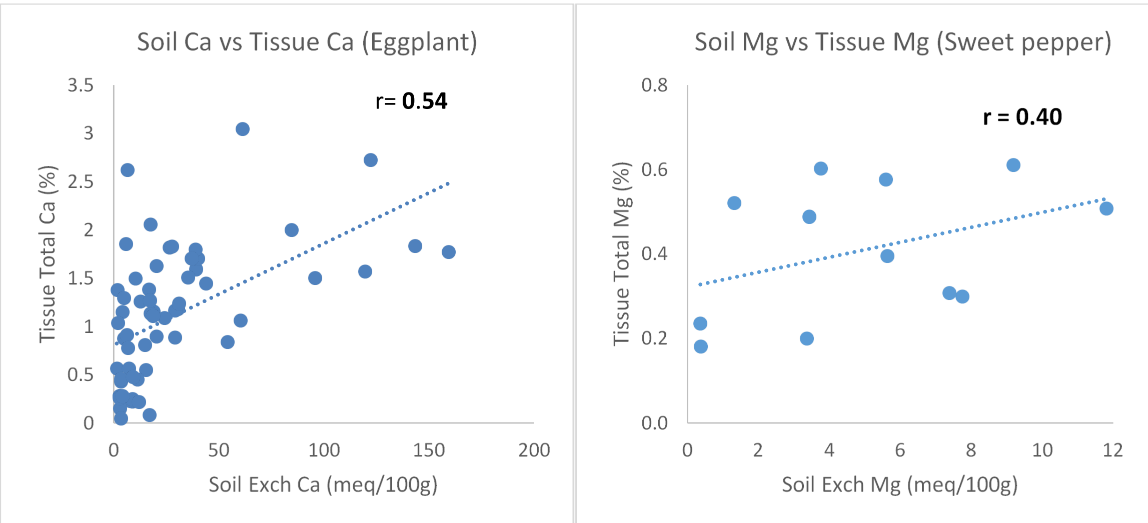


Figure 7.12. Relationship between vegetable tissue and soil concentrations for Ca and Mg in field survey in the Philippines.

Table 7.3. Mean, standard error (SE) and range data for plant tissue mineral concentrations for key vegetables (eggplant, sweet pepper, and tomato), in Davao region Philippines.

Element	Cabbage (2)	Eggplant (9)			Sweet Pepper (4)			Tomato (6)		
	Mean	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
N (%)	4.1	4.52	0.21	0.3-10.5	4.71	0.22	3.2-6.2	4.88	0.46	0.5-8.3
P (%)	0.47	0.79	0.08	0.26-2.73	0.53	0.14	0.23-2.4	0.50	0.09	0.3-1.61
K (%)	3.4	2.30	0.13	0.6-4.4	3.05	0.47	0.5-7.7	2.02	0.27	0.5-3.6
Ca (%)	1.0	1.39	0.07	0.42-3.04	1.29	0.11	0.64-1.91	1.72	0.11	1.03-2.38
Na (%)	0.39	0.04	0.02	0-0.7	0.10	0.06	0-0.7	0.18	0.07	0-0.7
Mg (%)	0.24	0.39	0.02	0.13-0.65	0.36	0.04	0.19-0.67	0.32	0.03	0.19-0.56
Fe (mg kg^{-1})	99.7	332	41.1	62-1316	288	48.8	86-713	204	29.4	79-457
Mn (mg kg^{-1})	95.7	99	23.0	14-933	162	45.7	17-600	149	32.8	17-434
Cu (mg kg^{-1})	28.3	33.1	2.32	11.7-89.9	28.7	4.35	10.7-64.5	36.3	5.67	11.9-83.2
Zn (mg kg^{-1})	23.0	27.9	1.57	13.6-81.1	29.8	2.69	13.5-55.1	24.2	2.14	13-44.1

SE denotes standard error
Bracketed values adjacent to the crop name are the sample number

Cabbage reference leaf survey

A survey of vegetable crop nutrient status, using cabbage as an index plant (youngest fully expanded wrapper leaf), was conducted in Leyte (Cabintan), and, Bukidnon, and Claveria (northern Mindanao). More than 75% of samples had tissue N, K and Ca concentrations above a sufficiency threshold (3% N, 3% K and 1.5% Ca) (Fig. 7.13). For the substantial vegetable production areas of Cabintan and Claveria the status of N and K was such that 100% of the interquartile ranges were above the sufficiency threshold. Indeed, in Claveria the complete interquartile range for K was greater than the range of either Cabintan or Bukidnon, with a minimum tissue K concentration of about 5% indicating very high K status and considerable potential to reduce K fertiliser inputs at Claveria. For Ca, 100% of the interquartile range of samples was sufficient for Claveria and Bukidnon. However, for Cabintan about 25% of samples were below the sufficiency threshold potentially reflecting a lower proportion of farmers applying lime or at rates lower than required.

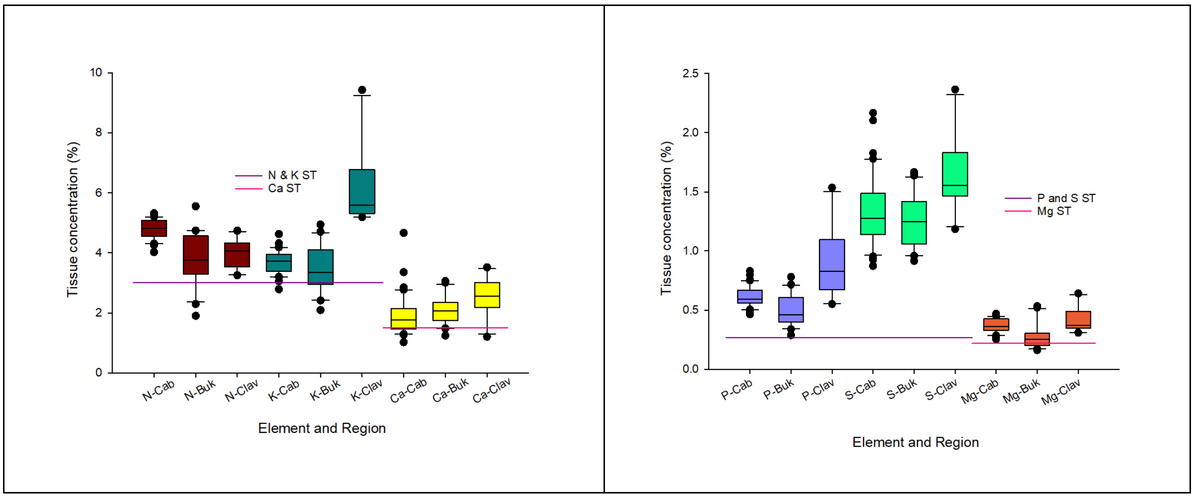


Figure 7.13. Box-plot distribution of N, K, and Ca concentrations (Left) and P, S, and Mg concentrations (right) in cabbage wrapper leaf samples collected from commercial farms in Cabintan (Cab), Bukidnon (Buk) and Claveria (Clav) the Philippines.

For P, at all sites 100% of the interquartile range was above the sufficiency threshold of about 0.3% (Fig. 7.13) indicating that banding of P fertiliser is effective in providing sufficient P to vegetable crops despite the bulk soil having low available P. For Claveria and Cabintan the complete interquartile range for Mg was above the sufficiency threshold but for Bukidnon the bottom 25% of samples had Mg concentrations below a sufficiency threshold of 0.25%. The high Mg concentrations for tissue samples from Claveria is not consistent with the soil Mg data for Claveria that indicated low Mg status. The adequacy threshold for Mg in cabbage is not well defined and values in the range of 0.18% to 0.60% are identified as the adequate concentration and values as high as 0.35% identified as deficient (Reuter and Robinson 1997). Given the discrepancy in reference data further research is required to delineate the status of Mg requirements for vegetable crops particularly in the acidic soils. Sulfur status in all samples was well above a sufficiency threshold of 0.25% (Fig. 7.13).

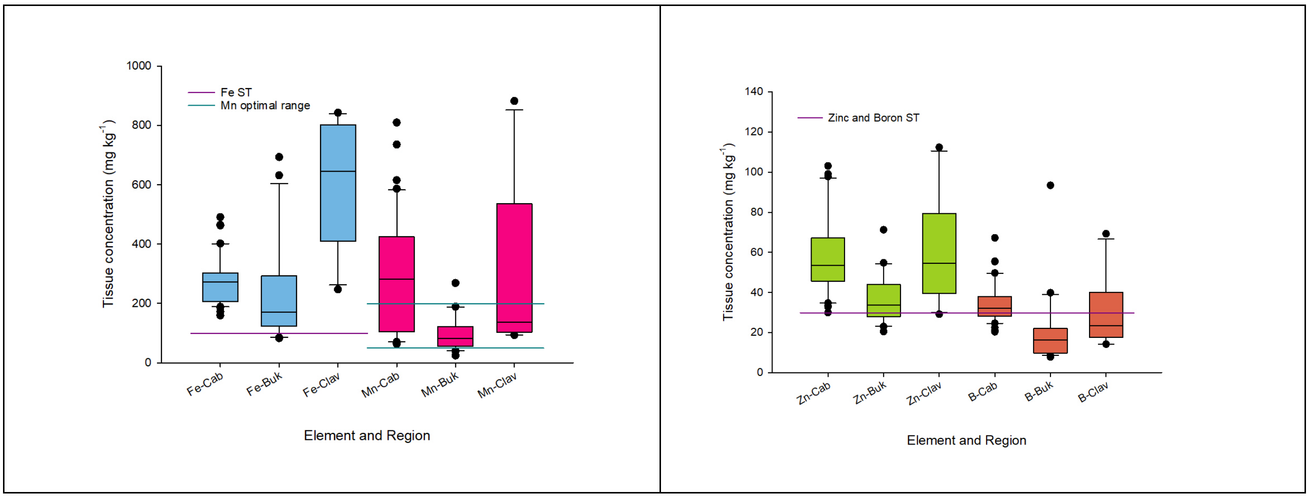


Figure 7.14. Box-plot distribution of Fe and Mn concentrations (Left) and Zn and B concentrations (right) in cabbage wrapper leaf samples collected from commercial farms in Cabintan (Cab), Bukidnon (Buk) and Claveria (Clav) the Philippines.

At all site the status of Fe and Mn was above a sufficiency threshold (Fig. 7.14). However, a high proportion of samples from Cabintan (>60%) and Claveria (>40%) had Mn concentrations above 200 mg kg^{-1} at which there would be concern over potential problems to crop growth due to excess Mn uptake (possibly Mn toxicity). The result for Claveria is consistent with the other plant tissue and soil data that indicated about 75% of samples had very high Mn concentrations. For Claveria and Cabintan, all of the interquartile range for tissue Zn concentration was above a sufficiency threshold of 30 mg kg^{-1} and for Bukidnon about 70% of samples were above the sufficiency threshold. The data for Claveria is consistent with the soil survey data where all soil samples were sufficient in Zn with a median soil Zn concentration of 6 mg kg^{-1}. The data for B showed that a considerable proportion of samples from each site, Cabintan (≈30%), Bukidnon (≈90%) and Claveria (≈60%) (Fig. 7.14), were below a sufficiency threshold of 30 mg kg^{-1} indicating B limitations are likely to negatively impact vegetable crop productivity. At Bukidnon, the B was low at an average of 21 mg kg^{-1}.

The Cu concentration in cabbage tissue samples from Cabintan and Claveria were very high with about 30-40% of samples being above the upper limit of the sufficiency range (8-15 mg kg^{-1}) (Fig. 7.15). It is possible that a proportion of this Cu may be present on the leaf surface as Cu-bactericide, however, the result for Claveria is consistent with the Claveria soil test data that shows excessive soil copper concentrations; a median concentration of about 6 mg kg^{-1}. In contrast to Claveria and Cabintan, the cabbage tissue Cu concentration at Bukidnon indicated marginal supply with 75% of samples below a sufficiency threshold of 6 mg kg^{-1}.

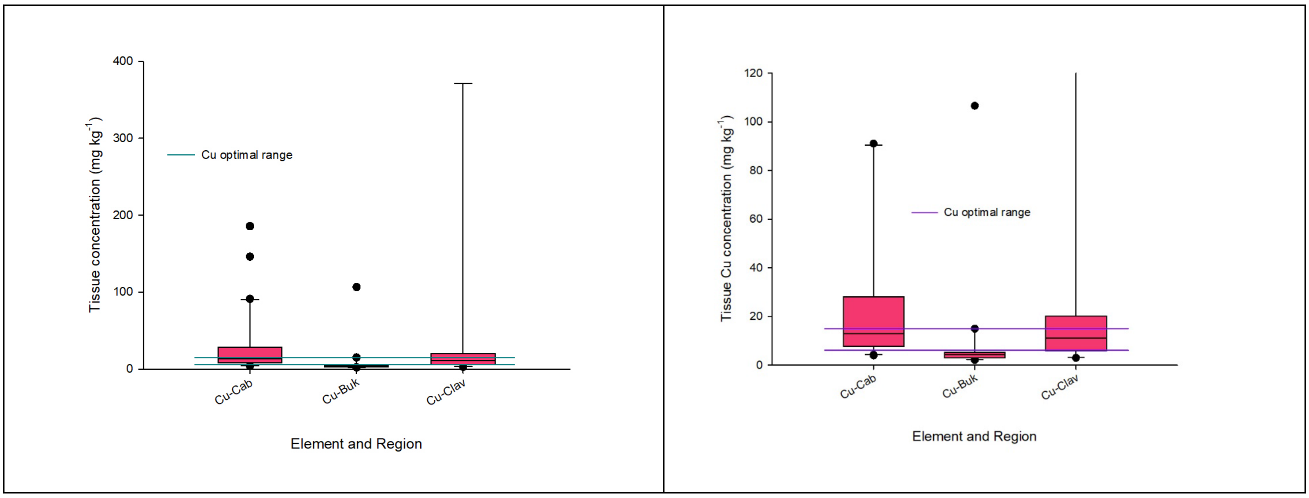


Figure 7.15. Box-plot distribution of Cu concentration (full range Left) and Cu concentration (0-120 mg kg^{-1} range right) in cabbage wrapper leaf samples collected from commercial farms in Cabintan (Cab), Bukidnon (Buk) and Claveria (Clav) the Philippines.

Across vegetable production sites based on acidic soils, there is high concentrations of Zn, Mn and Cu. These results certainly relate to the intensive nature of vegetable production activities that includes high application of pesticides containing Zn, Mn and Cu, and, the substantial contributions from chicken manure inputs. The estimates of inputs from Cu based bactericides would be about 6-7 kg Cu ha^{-1} per vegetable crop based on a single application of $Cu(OH)_2$ per week over 12 weeks of cropping. The estimates of Cu application from chicken manure are about 3.2 kg ha^{-1} based on chicken manure applications of 10 t ha^{-1} per annum and a Cu concentration 320 mg kg^{-1}. There is a need to more carefully manage chicken manure inputs to avert issues around food safety and heavy metal accumulation in vegetable production systems in the Philippines. Limited data in this project suggests that the response to chicken manure may be generally associated with micronutrient supplementation but chicken manure at recommended rates gives an unbalanced nutrient application program that results in soil accumulation of a range of mineral elements. Modifications in vegetable system nutrient management are required to ameliorate micronutrient limitations to crop growth but prevent excessive nutrient application. Improved crop rotation and specific micronutrient application, consistent with crop demand, and residue incorporation may reduce the requirements for chicken manure in vegetable production. The identification and characterisation of B and Mo limitations and responses to these elements in vegetable production systems is a key research issue.

A further part of the study compared nutrient status of 20 healthy and unhealthy samples collected from Cabintan. This data showed that there was essentially no difference in cabbage leaf tissue concentrations for N, P, K, Mg, Ca, S, Fe, Mn and Zn (data not presented) between the healthy and unhealthy samples. However, the concentrations of B in unhealthy samples tended to be lower than the healthy ones whilst the Cu concentration tended to be slightly higher (Figs 7.16). In this study Mo was not measured but has strong potential to limit vegetable crop productivity.

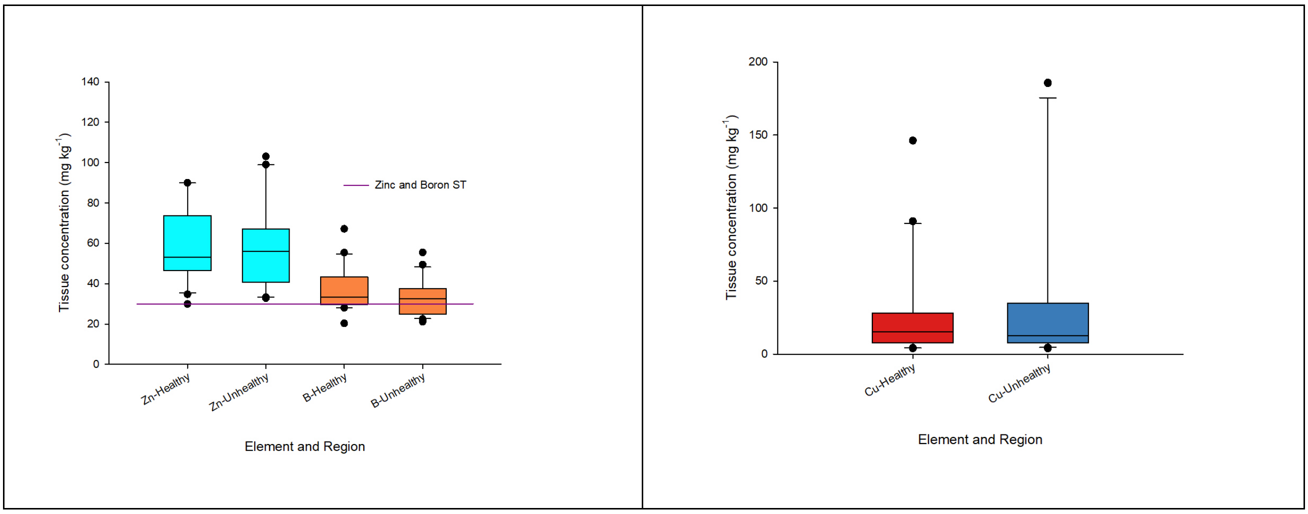


Figure 7.16. A comparison of Zn, B, and Cu concentration healthy and less healthy cabbage wrapper leaf samples collected from commercial farms in Cabintan the Philippines.

Table 7.4. Mineral concentrations for dried leaf samples of cabbage (youngest fully expanded wrapper leaf) collected form a survey of crops in Cabintan (Leyte) and Bukidnon and Claveria (Northern Mindanao).

Sample details			N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Na	Al
			%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Cabintan	Healthy	MN	4.72	0.62	3.55	1.87	0.37	1.24	249	271	67	37	28	967	192
		SE	0.06	0.02	0.08	0.12	0.01	0.06	16.8	37.1	11.2	2.5	8.0	80	21
		Range	4.30-5.25	0.46-0.75	2.78-4.19	1.26-2.84	0.27-0.46	0.87-1.82	160-465	63-615	30-268	20.3-67.2	4-146	512-1743	63-394
Cabintan	Unhealthy	MN	4.9	0.6	3.9	2.0	0.4	1.4	297	321	59	33	35	893	366
		SE	0.08	0.02	0.08	0.19	0.01	0.06	17.9	50.8	4.8	2.0	12.4	69.0	61.1
		Range	4.02-5.31	0.49-0.83	3.05-4.62	1.02-4.66	0.25-0.46	1.05-2.16	188-491	64-810	33-103	21.1-55.4	4-186	494-1575	78-1252
Bukidnon		MN	3.80	0.50	3.45	2.08	0.28	1.26	234	99	37	21	10	737	428
		SE	0.20	0.03	0.17	0.11	0.02	0.05	37.5	13.2	2.8	4.2	5.1	94	117
		Range	1.9-5.54	0.28-0.78	2.08-4.93	1.24-3.05	0.16-0.53	0.91-1.66	83-693	24-269	20-71.	7.83-93.4	2-107	184-2081	99-2416
Claveria		MN	3.9	0.42	6.1	2.3	0.90	1.6	598	299	61.6	29.2	51.5	1335	618
		SE	0.1	0.03	0.4	0.2	0.09	0.1	67	86	8.3	5.3	39	311	110
		Range	3.2-4.7	0.30-0.64	5.1-9.4	1.2-3.5	0.5-1.5	1.1-2.3	247-842	93-882	29-112	14.2-69.2	2.9-408	573-3680	178-1072

Nutrient omission experiments

A series of nutrient omission trials were conducted on three soil types for which the properties and classification are presented in Tables 7.5 and 7.6.

Table 7.5. Properties of soils collected from Cabintan, Claveria and Isabel used in a nutrient omission pot experiment at University of the Philippines Los Baños.

Parameter	Cabintan	Claveria	Isabel
Soil Classification	Andisol	Ultisol	Lithic Rendol Mollisol
Soil Series	Cabintan	Jasaan	Faraon
Parent Material	Volcanic ash	Basaltic andesitic volcanic materials	Limestone
Sample Location	Cabintan, Leyte	Claveria, Misamis Oriental	Isabel, Leyte
Soil Texture	Silt loam	Clay	Sandy loam
Soil pH (1:5 water suspension)	4.9	5.1	8.02
CEC	30.02	19.28	36.02
%MC at Field Capacity	62.68	44.56	45.8
% OM	9.27	3.7	4.14

Table 7.6. Nutrient Analysis of three soils collected from Cabintan, Claveria and Isabel used in a nutrient omission pot experiment at University of the Philippines Los Baños.

ELEMENT	METHOD OF EXTRACTION	SUFFICIENCY RANGE	ISABEL	CABINTAN	CLAVERIA
Total N %	Kjeldahl [1]	0.095-0.30	0.27	0.46	0.25
P mg kg^{-1}	Olsen[1]	5-10	26.00	-	-
P mg kg^{-1}	Bray[1]	10-15	-	10.00	10.00
K $cmol_c$ kg^{-1}	Ammonium acetate [1]	0.1-0.6	1.14	0.94	1.38
Ca $cmol_c$ kg^{-1}	Ammonium acetate [1]	5-20	24.35	0.63	3.17
Mg $cmol_c$ kg^{-1}	Ammonium acetate [1]	0.5-3	11.37	0.54	0.41
Fe mg kg^{-1}	DTPA[2]	4.0-10.0	15.84	141.90	85.76
Zn mg kg^{-1}	DTPA[2]	0.5-5.0	44.75	33.55	1.02
Mn mg kg^{-1}	DTPA[2]	0.5-3.5	60.50	150.50	10.07
Cu mg kg^{-1}	DTPA[2]	0.1-3.0	1.06	2.67	3.41

Nutrient omission trial

Cabintan soil.

Omission of P gave the strongest visible symptoms of nutrient limitation to plant growth, characterised by severe stunting. This was consistent with the soil and tissue analyses (Table 7.6 and 7.8), with a soil P concentration of 10 mg kg^{-1}, and a tissue P concentration of 0.06%. Notwithstanding, the tissue P concentration in the All+Lime treatment was only

0.16% and still below a critical value of about 0.25% indicating it was likely P was still limiting growth in the All treatment. There was a strong response to liming, where the plant dry mass in the All+Lime treatment (5.46 g) was greater than that in the All treatment (4.05 g) ($p<0.05$). The tissue concentration of maize from the Cabintan soil highlighted very low P concentrations of in the –P (0.06%) omission treatment compared with the All+Lime (0.16%). Though plant dry mass was greater in the All+Lime treatment the tissue P concentration would nonetheless indicate P deficiency. The 80 kg P ha^{-1} (equivalency) applied to the complete pots and other omission pots receiving P might not have been sufficient to maximise the P response. Thus a P limitation may have contributed to the low biomasses obtained in other omission treatments. Low maize tissue Ca concentrations (0.17%) and Mg concentrations were recorded in the –Ca and –Mg omission treatments compared with that of the All+Lime treatment (Table 7.8). Concentrations of both Ca and Mg would be below the critical sufficiency threshold despite a lack of plant growth response to the nutrient elements omission.

There was no significant differences between responses in the omission treatments (other than for P) compared with the All treatment (Table 7.7). However, lime was not applied to the omission treatments and a combination of a still low P status and lime response are likely to have reduced the effect of other mineral nutrient omissions. Notwithstanding, despite the lack of a statistical difference, plant dry mass in the –Mo and –K treatments was about 55-60% of that in the All treatment. The other plant tissue survey data highlighted consistently low plant tissue K status (Fig. 7.9).

Table 7.7. Dry matter biomass (g) of hybrid maize plants grown in a nutrient omission pot experiment in soil collected from Cabintan and Isabel, conducted at University of the Philippines Los Baños.

TREATMENT	CABINTAN Dry Biomass (g)		ISABEL Dry Biomass (g)	
ALL	4.05	b	4.21	a
ALL+ Lime	5.46	a	-	
- N	3.77	b	3.19	ab
- P	1.68	d	0.99	c
- K	2.24	bc	3.09	ab
- Ca	3.53	bc	3.17	ab
- Mg	4.04	ab	3.15	ab
- S	3.79	b	2.91	b
- Fe	3.99	b	3.88	ab
-Cu	3.1	bc	2.62	b
- Zn	3.91	b	1.74	b
- Mn	2.68	bc	2.86	b
- Mo	2.35	bc	2.91	b
- Ni	2.5	bc	3.08	ab
-Co	3.52	bc	3.26	ab
-B	3.55	bc	3.25	ab

Table 7.8. Plant tissue concentrations of hybrid maize plants grown in a nutrient omission pot experiment in a soil collected from Cabintan.

	N %	P%	K%	Ca%	Mg%	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}	Cu mg kg^{-1}
Sufficiency Range	3.5-5.0	0.4-0.8	3.5-5.0	0.9-1.6	0.3-0.8	50-300	50-160	20-50	7-20
Cabintan soil									
Optimal treatment (All+Lime)	3.2	0.16	7.5	0.52	0.53	78	66	44.0	9.9
Omission treatment	-N 3.1	-P 0.06	-K 6.4	-Ca 0.17	-Mg 0.20	-Fe 61	-Mn 134	-Zn 50.0	-Cu 15.3
Isabel soil									
ALL	2.3	0.18	7.5	0.80	0.32	111	39	29.4	14.1
Omission treatment	-N 2.7	-P 0.31	-K 7.3	-Ca 0.85	-Mg 0.28	-Fe 150	-Mn 36	-Zn 18.5	-Cu 14.0

The response of maize plants to the nutrient omission treatments in the calcareous Isabel soil was first evident in the –P omission treatment at 3 weeks after sowing and by the 4th week visual nutritional deficiency symptoms were observed in the -S, -Zn, -Cu, -Mn and -Mo treatments. The dry biomass data (Table 7.7) highlighted strong growth reductions in the –P (76.5% reduction) and –Zn (58.7% reduction) omission treatments. The -S, -Cu, -Mn and -Mo treatments also had reduced biomass compared with the All treatment. The maize tissue N and P concentrations in the All treatment were below the sufficiency thresholds for N (3.5%) and P (0.4%). This indicates, in the calcareous Isabel soil, there is a need to increase the level of N and P application for ALL pots and omission treatment pots containing P. The concentration of elements in the –N, -P, -Mg and –Zn omission treatments suggests these elements are low or deficient in plant tissue in the calcareous soil (Table 7.8).

Claveria soil

An omission trial was conducted on an acidic soil from Claveria using three test species including cabbage, sweet pepper, and hybrid maize.

In cabbage, the first symptoms expressed were those of P deficiency at 40 DAS and biomass yield in the –P treatment was reduced by 86% compared with the ALL treatment (Table 7.9). Though not a significant effect, the biomass yield in the -Cu and –S treatments appeared to be lower than that in the All treatment. Sulfur has been recognised as an important nutrient for optimum growth and development of high S demand plants such as cabbage. With the exception of the nil fertiliser control the cabbage leaf P concentration was lowest in the -P treatment (0.33%) compared with the All+lime treatment (0.46%). Similarly, the Cu concentration in cabbage leaf tissue was 4.7 mg kg^{-1} in the –Cu treatment compared with 7.0 mg kg^{-1} in the All+Lime treatment. A Cu concentration of 7.0 mg kg^{-1} is lower than the leaf concentration considered marginal for cabbage (Bennett 1993) suggesting a higher Cu rate was required to maximise biomass yield in the All treatment and this may have impacted on the overall results.

Table 7.9. Dry matter biomass (g) of cabbage, sweet pepper and maize plants grown in a nutrient omission pot experiment in soil collected from Claveria.

TREATMENT	CABBAGE (g/pot)		SWEET PEPPER		MAIZE	
Control	0.02	d	0.66	c	14.34	g
ALL	3.61	abc	1.86	ab	26.55	ab
ALL+Lime	5.41	a	3.25	a	27.06	a
-N	3.62	abc	0.56	c	18.88	def
-P	0.75	cd	0.91	c	17.62	efg
-K	2.45	abcd	1.37	c	23.61	abc
-Ca	3.9	abc	1.67	b	20.43	cdef
-Mg	3.59	abc	1.24	c	21.73	cdef
-S	2.73	abcd	1.42	bc	22.09	bcde
-Fe	3.52	abc	3.18	a	22.25	bcd
-Mn	4.53	ab	1.98	bc	18.99	def
-Zn	2.39	abcd	1.44	c	17.45	fg
-Cu	1.87	abc	1.75	bc	23.25	abcd
-B	3.84	abc	1.75	bc	22.91	abcd
-Mo	4.02	abc	0.99	c	20.67	cdef
-Ni	1.85	bcd	1.41	c	20.61	cdef
-Co	2.71	abc	1.91	bc	21.91	cdef

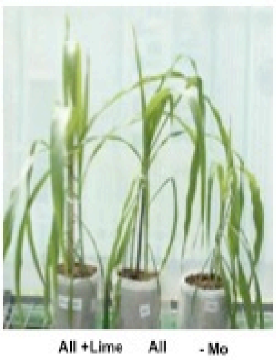
Table 7.10. Plant tissue concentrations of hybrid maize plants grown in a nutrient omission pot experiment in a soil collected from Claveria.

	N %	P%	K%	Ca%	Mg%	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}	Cu mg kg^{-1}
Cabbage									
ALL+Lime	4.63	0.46	4.5	3.12	0.1	198	23	20.3	7
Omission treatment	-N	-P	-K	-Ca	-Mg	-Fe	-Mn	-Zn	-Cu
	3.6	0.33	4.7	3.1	0.10	156	83	20.0	4.7
Sufficiency Range**	2.5-5.0	0.2-0.5	3.5-5.0	0.9-1.6	0.3-0.8	50-250	20-300	20-100	5-20
Sweet Pepper									
ALL+Lime	4.68	0.25	3.07	1.06	0.12	144	178	29.1	15.3
Omission treatment	-N	-P	-K	-Ca	-Mg	-Fe	-Mn	-Zn	-Cu
	4.31	0.2	2.47	0.91	0.10	102	139	27.0	14.3
Sufficiency Range**	3.0-5.0	0.3-0.7	3 -5.5	0.3-1.2	0.3-1.2	60-300	50-250	20-200	6-200
Maize									
All+ Lime	2.2	0.28	6.4	0.31	0.04	115	43	19.3	5.2
Omission treatment	-N	-P	-K	-Ca	-Mg	-Fe	-Mn	-Zn	-Cu
	1.7	0.27	4.8	0.27	0.04	106	93	22.4	5.7
Sufficiency Range*	3.5-5.0	0.4-0.8	3.5-5.0	0.9-1.6	0.3-0.8	50-300	50-160	20-50	7-20

* Nutrient Deficiencies and Toxicities in Crop Plants by W.F. Bennett, 1993 by APS Press
**Weir and Cresswell, 1993

In sweet pepper, visual evidence of nutrient deficiency were observed in the -N, -P and –Mo treatments at 60 DAS and included stunting and yellowing. These visual symptoms were supported by the dry matter data where there was a significant reduction in dry matter in the –N, -P and –Mo treatments compared with the All+Lime (Table 7.9). For sweet pepper there were omission responses to all nutrients with the exception of Fe (Table 7.9). However, these dry matter responses were not consistent with the nutrient concentration data where there was essentially no difference in the leaf concentrations of the omitted nutrient in the omission treatments and the same element in the All+Lime (table 7.10). For example, the tissue Zn concentration in the –Zn treatment was 27.0 mg kg^{-1} and in the All+Lime the tissue Zn concentration was 29.1 mg kg^{-1}. Notwithstanding, the –Mo treatment had a biomass similar to the –P treatment and in the absence of leaf Mo concentration data it is possible that the Mo application in all treatments (except the –Mo) may not have been sufficient to maximise biomass production, and Mo may still have been limiting growth. The response to Mo in sweet pepper and lack of response in cabbage is somewhat inconsistent, in that brassicas have a relatively high Mo demand and often express Mo deficiency under low Mo status.

In maize, the first evidence of deficiency occurred at 30DAP in the –P treatment and a substantial reduction in biomass was recorded in the –P, and –Zn treatments (Table 7.9). Despite these responses there was no apparent difference in the concentrations of P and Zn between the omission treatments and the All+Lime treatment suggesting that higher basal applications of both elements, but particularly P, may have been required to fully alleviate the deficiency and provide concomitant increases in tissue P and Zn concentrations. The sufficiency threshold for P is about 0.4% and the maize leaf P concentration in the All+Lime was only 0.28%, whilst, the sufficiency threshold for Zn is 20 mg kg^{-1} and the leaf Zn concentration in the All+Lime was marginal at 19.2 mg kg^{-1}. There were also reductions in biomass in the –N treatment and chlorosis symptoms due to N deficiency were visible at 35 DAS. There was no response to K application which was substantiated by the initial K status of the soil (1.38 cmol kg^{-1}) and maize plant tissue concentration (4.8 %) which is in the sufficiency range. At 60 DAS, there was a significant reduction in biomass in the N, P, Ca, Mg, Mn, Zn, Mo, Ni, Co omission treatments.



Intensive vegetable production effects on soil properties of an Andisol.

A survey of vegetable soil properties was conducted on Andisols in Leyte and compared with an uncleared forest reference soil (Fig. 7.17). The particle size distribution of the soils from all 12 sites classed as loamy sand to sandy loam texture (Fig.7.17) indicating a dominance of coarse soil pores and excellent drainage. This type of soil texture is typical of Andisols because they are still in the early stage of soil development. The very high rainfall and the heavy fertiliser application is likely to result in strong leaching of applied nutrients.

Soil pH values ranged from 4.14 to 6.13 with an average value of 5.37 (Fig. 7.18). The soil pH of site 12 (the reference site) at the surface was moderately acidic (pH 5.5) due to the high organic matter content but decreased in the mid-section of the soil profile (B horizon). The soil pH at other vegetable sites was highly variable. For example site 2 had a uniform pH of about 6 throughout the profile while for site 10 pH was between 4.5 and 5 throughout the profile. This likely reflected different levels of soil management by vegetable farmers.

The soil organic matter content of the reference soil site 12 was the highest of all sites (~12-13%) particularly in the surface soil but declined substantially in the subsoil (Fig. 7.18). Several sites (sites 1, 3, 5, 8, 10, and 11) showed a similar trend in organic matter to site 12 though they have lower SOM content in the topsoil. Some sites (sites 2, 4, 6 and 7) had low SOM in the surface soil but with considerable SOM in the subsoil. This suggests that under intensive vegetable production surface SOM content declines but with frequent manure application there is an accretion of SOM in the subsoil. The decomposition of organic matter in the subsoils of Andisols is acknowledged as being slowed under high active Al through the formation of humus-metal complexes (Shoji et al. 1992, Asio 1996 and Chen et al. 1999).

As is typical for Andisols, the reference site 12 had extremely low P concentration due to the high P fixing capacity of Andisols (Shoji et al., 1993; Asio, 1996; Chen et al., 1999) (Fig. 7.18). However, all the other sites and particularly sites 2, 3, and 4 had considerably higher available P contents than the reference site. This was indicative of improved P availability with continuous application of high rates of P fertilizer along with chicken manure application.

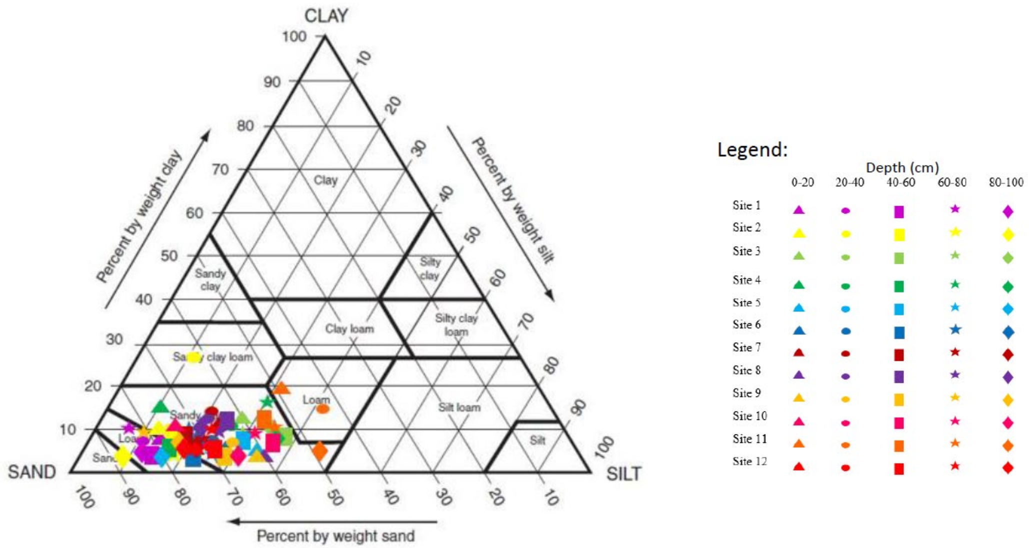


Figure 7.17. Differences in Andisol soil properties (pH, organic matter, total N and total P) with soil depth in samples collected from 12 sites in Cabintan Leyte. Sites 1-11 are cultivated to vegetables and reference Site 12 is a native uncleared forest site.

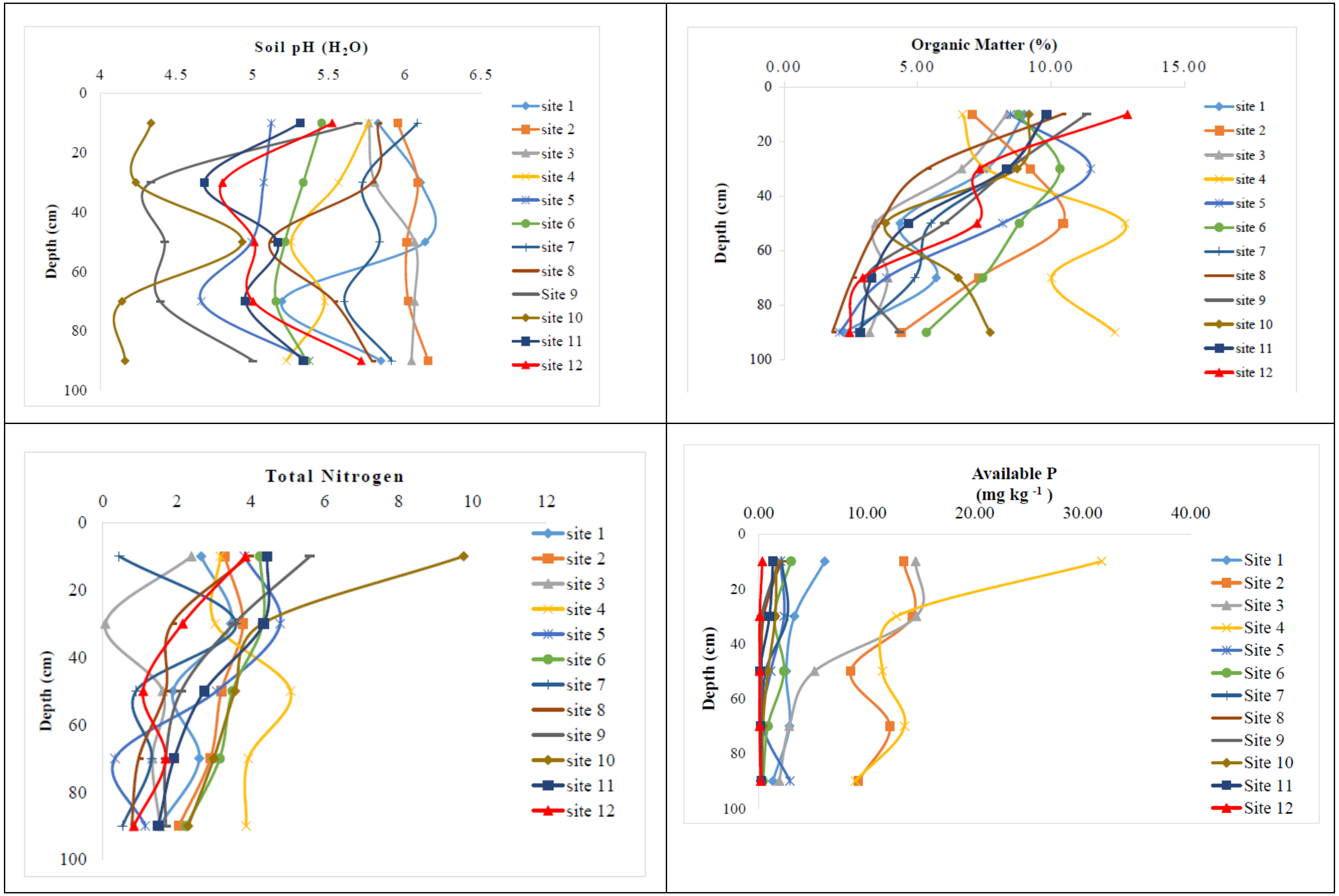


Figure 7.18. Differences in Andisol soil properties (pH, organic matter, total N and total P) with soil depth in samples collected from 12 sites in Cabintan Leyte. Sites 1-11 are cultivated to vegetables and reference Site 12 is a native uncleared forest site.

7.2 Evaluation of organic production strategies for crop nutrition.

Field experimentation comparing yield under organic and conventional production.

A series of experiments evaluated the effects of combinations of organic and synthetic fertiliser (OF and SF), and biopesticides (BP) or synthetic pesticides (SP) strategies. The experiments were conducted over two cropping cycles on a range of vegetable crops including tomato, eggplant sweet pepper, and cabbage. As described in the methods the experimental treatments included the following treatments

1. Control – No added fertilisers or amendments.
2. Full Organic production system (OF&BP)[*in compliance with the Philippine National Standards on Organic Agriculture-PNS-OA*].
3. Full Conventional production system (SF&SP)(*synthetic fertilisers and synthetic pesticides*).
4. Organic fertilisers combined with synthetic pesticides (OF&SP).
5. Synthetic fertilisers combined with biopesticides/bio-control agents (SF&BP).
6. A combination of synthetic fertilisers and organic fertilisers with synthetic pesticides (OF&SF&SP).
7. A combination of synthetic and organic fertilisers with bio-pesticides/bio-control agents (OF&SF&BP).

The yield of all test crops (tomato, sweet pepper, eggplant and cabbage) showed a consistent yield response pattern to treatments over the course of the experiments (Tables 7.11, 7.12, 7.13 and 7.14). The response to synthetic fertilisers in the 2 tomato experiments was unambiguous where all treatments receiving the SF gave total yields of 16-17 t ha^{-1} (Experiment 1) and 17-21 t ha^{-1} (Experiment 2). In contrast, across the 2 experiments, the yield of treatments that only received organic fertiliser was only 6-10 t ha^{-1}. From a crop nutrition perspective organic fertilisers do not provide sufficient major nutrients to meet high crop yield. For eggplant the difference in yield between treatments was less pronounced where total yield for the organic fertiliser treatments was about 12-15 t ha^{-1} and the yield in the synthetic fertiliser treatments was about 18-22 t ha^{-1}. This may relate to the more vigorous and extensive root system eggplant has. Overall, yields for sweet pepper were low but application of synthetic fertiliser gave yields that were 2-3 times greater than that with organic fertiliser only.

The effect of pesticide management on total yield varied from crop to crop. In tomato, yield for the OF+SF+SP treatment (17.4 t ha^{-1} 1st crop and 20.6 t ha^{-1} 2nd crop) was similar to that for the OF+SF+BP treatment (16.5 t ha^{-1} 1st crop and 21.0 t ha^{-1} 2nd crop). In sweet pepper, though the effect in experiment 1 was not significant, the total yield for the OF+SF+SP treatment (22.0 t ha^{-1} 1st crop and 24.7 t ha^{-1} 2nd crop) was about 6 t ha^{-1} greater than that for the OF+SF+BP treatment (16.3 t ha^{-1} 1st crop and 18.6 t ha^{-1} 2nd crop). Apart from the impact of fertiliser form on crop yield, pest management had an important effect on plant yield potential (plant health) and not simply a direct pest impact on fruit quality *per se*. The marketable fruit yield also confirmed that fruit quality losses were greater in the OF+SF+BP treatment where the marketable yields for the first crop (10.3 t ha^{-1}) and second crop (12.2 t ha^{-1}) were about only 60-65% of that in the OF+SF+SP treatment.

A similar effect to this was observed for cabbage head yield. The total head yield of cabbage for the OF+SF+SP treatment (46.0 t ha^{-1} 1st crop and 38.9 t ha^{-1} 2nd crop) was substantially greater ($p<0.01$) than that for the OF+SF+BP treatment (35.3 t ha^{-1} 1st crop and 27.6 t ha^{-1} 2nd crop). This effect is specifically ascribed to the impact of diamond back moth that greatly reduces biomass yield of cabbage and subsequent head growth.

Across all crop species there was no yield difference between the Full Conventional treatment and the OF+SF+SP (Conventional with manure) indicating that the observed response to the mineral fertilisers is mostly due to the major elements and most likely P (Fig. 7.19).

Table 7.11. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) on the marketable, non-marketable and total yield of Tomato in a field experiment conducted at Bukidnon, Mindanao The Philippines.

TREATMENTS	Yield 1st Cropping (t ha^{-1})			Yield 2nd Cropping (t ha^{-1})		
	Marketable	Non-marketable	Total	Marketable	Non-marketable	Total
Control	1.6 c	2.0 b	3.3 b	2.8 c	3.7 b	6.5 b
OF+BP (Full Organic)	4.8 c	2.5 b	7.3 b	6.5 bc	3.6 b	10.1 b
SF+SP (Conventional)	13.3 ab	3.6 ab	16.9 a	14.0 a	5.8 a	19.8 a
OF+SP	4.0 c	1.9 b	5.9 b	4.9 c	3.1 b	8.0 b
SF+BP	9.6 b	5.4 a	16.0 a	11.0 ab	6.1 b	17.1 a
OF+SF+SP	14.2 a	3.2 ab	17.4 a	15.9 a	4.7 b	20.6 a
OF+SF+BP	10.9 ab	5.6 a	16.5 a	13.8 a	7.2 a	21.0 a

Table 7.12. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) on the marketable, non-marketable and total yield of eggplant in a field experiment conducted at Bukidnon, Mindanao The Philippines.

Treatments	Yield 1st Cropping (t ha^{-1})			Yield 2nd Cropping (t ha^{-1})		
	Marketable	Non-marketable	Total	Marketable	Non-marketable	Total
Control	5.4 c	3.3 c	8.7 d	6.7 d	3.3 d	10.0 e
OF+BP (Full Organic)	7.9 bc	4.5 bc	12.4 cd	9.5 cd	4.4 cd	13.9 de
SF+SP (Conventional)	12.5 ab	5.9 ab	18.4 abc	17.5 ab	5.8 abc	23.3 ab
OF+SP	8.6 bc	5.1 abc	13.6 bcd	10.3 cd	5.2 bc	15.5 cde
SF+BP	12.5 ab	6.7 a	19.2 ab	14.1 abc	7.1 a	21.2 abc
OF+SF+SP	16.5 a	5.5 ab	22.0 a	19.0 a	5.7 abc	24.7 a
OF+SF+BP	10.3 bc	6.0 ab	16.3 abc	12.2 bcd	6.4 ab	18.6 bcd

Table 7.13. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) on the marketable, non-marketable and total yield of sweet pepper in a field experiment conducted at Bukidnon, Mindanao The Philippines.

Treatments	Yield 1st Cropping (t ha^{-1})			Yield 2nd Cropping (t ha^{-1})		
	Marketable	Non-marketable	Total	Marketable	Non-marketable	Total
Control	0.2 d	0.2 c	0.4 c	0.5 c	0.4 a	0.9 b
OF+BP (Full Organic)	0.3 cd	0.2 c	0.5 c	1.1 b	0.6 cd	1.7 b
SF+SP (Conventional)	1.6 a	0.4 b	2.0 a	2.6 a	0.9 ab	3.5 a
OF+SP	0.5 c	0.2 c	0.7 c	1.0 bc	0.5 cd	1.5 b
SF+BP	0.8 b	0.8 a	1.6 b	1.2 a	1.5 bcd	2.7 a
OF+SF+SP	1.6 a	0.5 b	2.1 a	2.7 a	0.8 a	3.5 a
OF+SF+BP	0.9 b	0.6 b	1.5 b	1.5 a	1.1 abc	2.6 a

Table 7.14. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) on the marketable, non-marketable and total yield of cabbage in a field experiment conducted at Bukidnon, Mindanao The Philippines.

Treatments	Yield 1st Cropping (t ha^{-1})			Yield 2nd Cropping (t ha^{-1})		
	Marketable	Non-marketable	Total	Marketable	Non-marketable	Total
Control	8.8	8.3	17.1 e	5.7	5.1	10.8 d
OF+BP (Full Organic)	10.8	12.8	23.6 e	7.0	9.1	16.1 c
SF+SP (Conventional)	40.1	7.4	47.5 a	36.4	3.7	40.1 a
OF+SP	17.0	10.6	27.6 de	13.2	6.9	20.1 b
SF+BP	19.9	16.9	36.8 cd	16.3	13.2	29.5 b
OF+SF+SP	38.5	7.5	46.0 ab	34.6	4.3	38.9 a
OF+SF+BP	14.5	20.8	35.3 cd	10.8	16.8	27.6 b

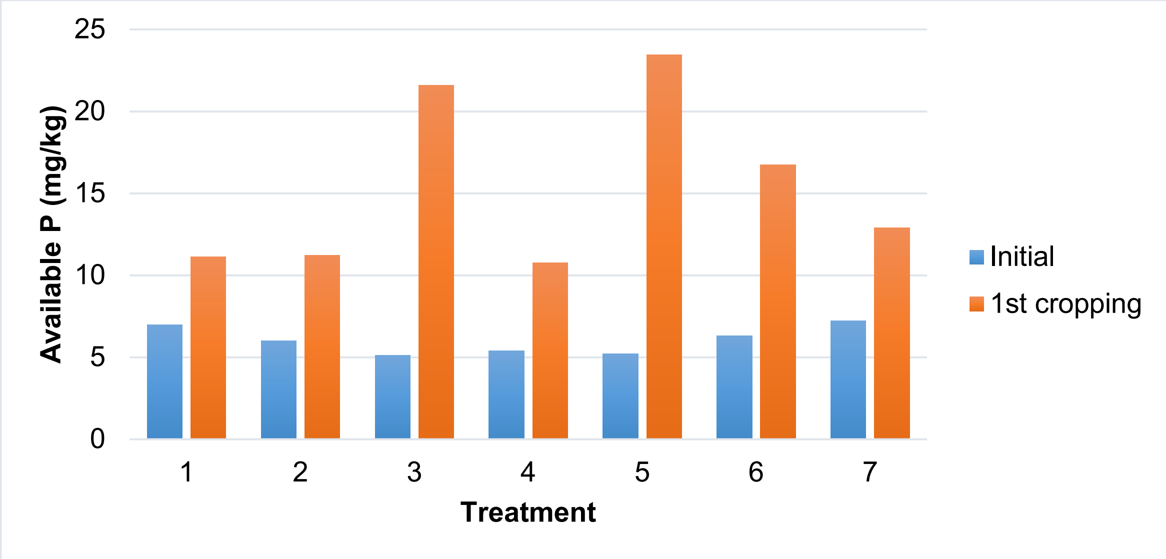


Figure 7.19. Differences in soil available P concentration after a range of treatments were imposed in field experiments on tomato, eggplant, sweet pepper, and cabbage conducted at Bukidnon, Mindanao The Philippines. The treatments imposed consisted of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) including a control (T1), OF+BP (T2), SF+SP (T3), OF+SP (T4), SF+BP (T5), OF+SF+SP (T6) and OF+SF+BP (T7).

A comparison of the effect of bio-pesticides and synthetic pesticides on fruit quality was made by calculating the percentage marketable yield for each crop species (Fig. 7.20). Synthetic fertilisers, apart from their positive effects on yield, gave the highest proportion of marketable product for each crop species. For tomato, eggplant, and sweet pepper the proportion of marketable product ranged from 75-81% in the OF+SF+SP treatment compared with 60-66% in the OF+SF+BP highlighting that the organic pest management options do not control pests to the same extent as the synthetic pesticides. This difference was even greater for cabbage where the proportion of marketable product was 80% across the 2 cropping cycles in the OF+SF+SP treatment compared with only 40% in the OF+SF+BP treatment. The substantial damage from diamond back moth greatly reduced both total yield and the proportion of total yield that is marketable. New strategies to address crop nutrition and pest management are required to improve productivity limitations in organic vegetable production systems.

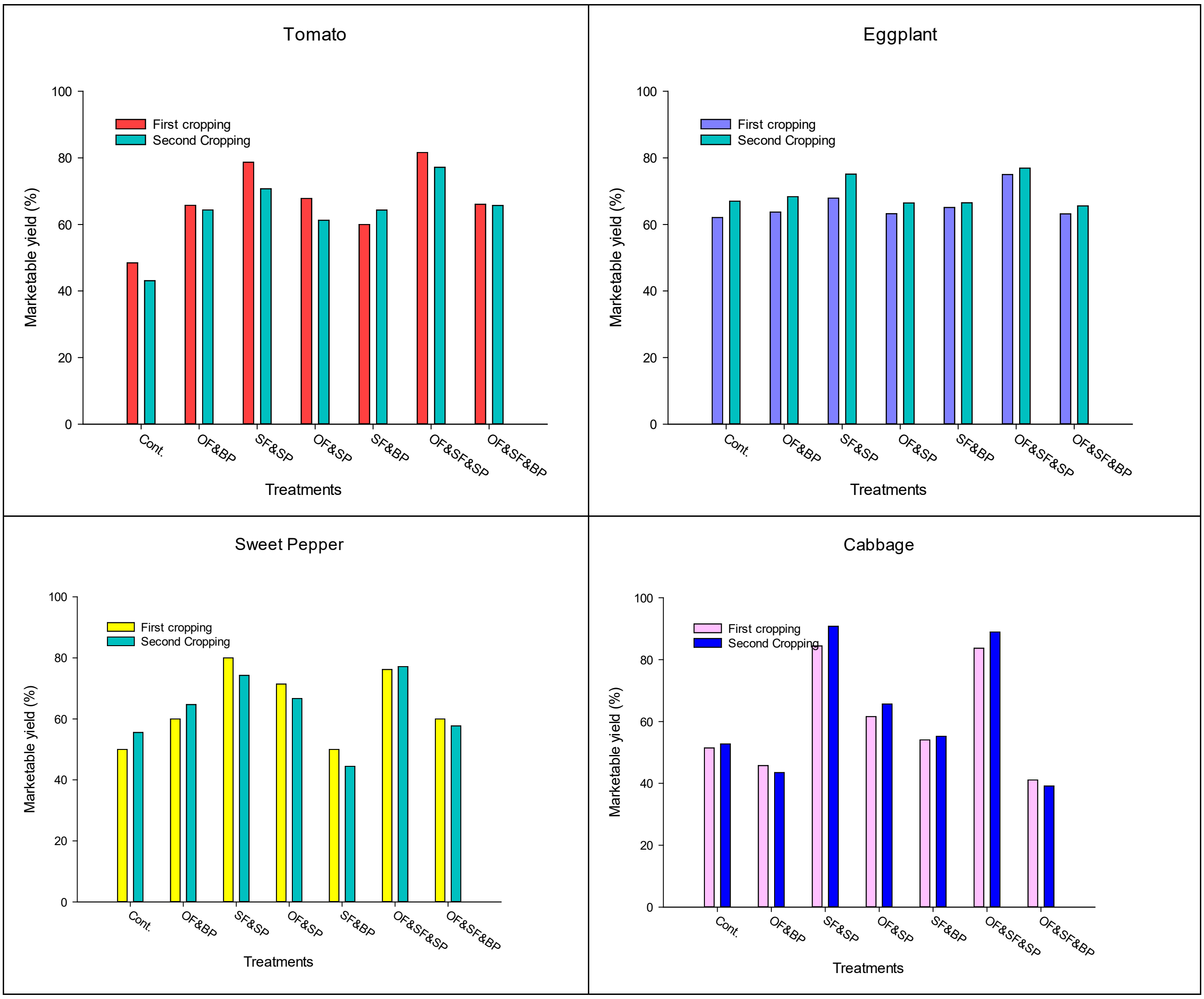


Figure 7.20. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) treatments on the proportion of total yield that can be marketed in field experiments on tomato, eggplant, sweet pepper and cabbage conducted at Bukidnon, Mindanao the Philippines.

The incidence of pests and diseases was evaluated in tomato for two pathogens, Tomato yellow leaf curl virus (TYLCV) and Early Blight (*Alternaria solani*), using a rating scale of 1-5. Early blight incidence data at the early stages of crop development, when incidence was low, had high coefficients of variation (CV) and incidence could not be directly related to the imposed treatments (data not presented). For TYLCV assessments, the CVs were also high, however, treatments that received organic fertiliser in combination with synthetic pesticides tended to have lower TYLCV incidence particularly at the final evaluation (Table 7.15). During the first data gathering (week 1), highest TYLCV incidence (32.0%) was observed in the synthetic fertilisers with bio-pesticides treatment while the lowest incidence (10.9%) was observed in the Control. At the last sampling (week 3), incidence was high across all treatments but significant differences were nonetheless observed across treatments. The synthetic fertilisers combined with bio-pesticides recorded 100% infection. In treatments where organic fertilisers were applied, the incidence of TYLCV tended to be lower.

Table 7.15. Effects of combinations of synthetic fertilisers (SF), organic fertilisers (OF), synthetic pesticides (SP) and bio-pesticides (BP) treatments on the incidence of tomato yellow leaf curl virus in a field experiment on tomato conducted at Bukidnon, Mindanao The Philippines.

Treatments	Disease Incidence (%)	
	Week 1 **	Week 3a **
Control	10.9 b	86.7 abc
OF+BP (Full Organic)	17.2 ab	68.3 c
SF+SP (Conventional)	27.3 ab	85.0 abc
OF+SP	17.2 ab	73.3 bc
SF+BP	32.0 a	100.0 a
OF+SF+SP	14.1 ab	76.7 bc
OF+SF+BP	24.2 ab	94.2 ab

Experimentation comparing organic and conventional practices has shown that organic based systems that rely solely on organic nutrient input do not achieve yields that are achieved in systems where mineral nutrient sources are used. Systems that rely on organic nutrient forms alone produce less than half the fruit number of systems that use mineral fertiliser (also in combination with organic fertilisers). A well-managed conventional production system, that uses both mineral and organic nutrient sources, produced about 5 times the yield of systems where the sole source of nutrient is organic. Furthermore, for peppers the organic production systems have a delayed harvest date of up to 14 days.

Effects of chicken manure rates on eggplant

The effects of chicken manure alone on the growth, yield and fruit quality in two eggplant cultivars was evaluated in a pot experiment. The aim was to identify the rate of chicken manure that optimises crop growth under organic production. The application of chicken manure at rates of 200-800 g plant^{-1} reduced the time to first flowering and first harvest compared with the control treatment and treatments with chicken manure at 100-1,600 g plant^{-1} (Table 7.16). No significant difference was observed on plant height across the treatments at the flowering stage, but significant differences were observed at the final harvest. Maximum plant height was obtained at an application rate of 800-1,000 g chicken manure plant^{-1} and was substantially greater than that in the 0-400 g plant^{-1} treatments. There was no difference between cvs. Morena and Casino in days to first flowering or first harvest but plant height for Morena was consistently greater than for Casino (Table 7.16).

Table 7.16. Effects of chicken manure (CM) rate (0-1,600 g plant^{-1}) on the time to first flower initiation and first harvest and on plant height at first flowering and final harvest of eggplant in a pot experiment conducted at Leyte The Philippines.

CM rate (g plant^{-1})	Time to 1st flowering (DAT)	Time to 1st harvest (DAT)	Plant Height 1st Flowering (cm)^{NS}	Plant Height Final Harvest (cm)
Control	42.9 a	63.9 a	19.1	68 d
200	31.7 c	47.0 d	18.9	98 c
400	32.3 bc	47.7 cd	19.1	118 b
600	33.6 bc	49.9 cd	18.5	129 ab
800	35.1 b	51.5 c	18.9	135 a
1000	41.5 a	58.1 b	18.7	134 a
1600	42.1 a	58.4 b	18.1	129 ab
C.V. (%)	5.1	4.4	6.9	5.8
Genotypes				
Casino	37.0	53.4	17.9 b	110 b
Morena	37.1	54.2	19.6 a	121 a
C.V. (%)	7.2	5.3	8.1	6.7

Treatment means with the same letter are not significantly (p=0.05)
^{NS} Denotes treatment effects not significant at p<0.05.

Table 7.17. Effects of chicken manure (CM) rate (0-1,600 g plant^{-1}) on mean fruit length (cm), marketable fruit number per plant (Mkt No.), marketable fruit weight per plant (Mkt Wt.) and marketable fruit yield (Mkt Yld) of eggplant grown in a pot experiment conducted at Leyte The Philippines.

CM rate (g plant^{-1})	Fruit Length (cm)	Mkt No. (fruit plant^{-1})	Mkt Wt. (kg plant^{-1})	Mkt Yld (t ha^{-1})
Control	15.9 b	1.3 d	0.1 c	1.0 c
200	19.2 a	12.2 bc	1.0 b	14.9 b
400	21.2 a	16.5 a	1.5 a	20.6 a
600	21.1 a	14.6 a	1.3 a	19.3 a
800	20.4 a	14.4 ab	1.3 a	18.8 a
1000	20.1 a	10.3 c	0.9 b	14.7 b
1600	21.2 a	10.8 c	1.0 b	15.3 b
C.V. (%)	9.2	12.5	10.5	11.4
Genotypes				
Casino	19.8	11.9 a	1.02	15.5 a
Morena	19.9	11.0 b	0.98	14.4 b
C.V. (%)	12.7	14.6	13.9	12.2

Treatment means with the same letter are not significantly (p=0.05)

Application of chicken manure at 400-800 g plant^{-1} gave substantial increases in marketable fruit number per plant, marketable fruit weight per plant and marketable fruit yield compared with other treatments (Table 7.17). The fruit length was lower in the Control compared with other treatments but overall chicken manure application from 200-1600 g plant^{-1} did not affect fruit length. Eggplants applied with chicken manure at 400–800 g plant^{-1} produced a greater fruit number and heavier fruits, consequently giving the highest total yield. At the reproductive (fruit production) stage more nutrients are required for the desired number and biomass of fruits evident in the smallest number and size of fruit in the absence of chicken manure application. Higher application rates of chicken manure supply greater amounts of nutrient to meet plant demand. Cultivar Casino had greater plant vigour than cv. Morena with taller plants, greater fruit number per plant and higher yield.

The optimal chicken manure application rate was about 400-800 g plant^{-1} which based on a plant population of 12,500 plants ha^{-1} equated to rates of about 5-10 t ha^{-1}. Marketable yield dropped substantially with a further increase in chicken manure application from 800 g plant^{-1} to 1000 g plant^{-1} equivalent to rates of 10 and 12.5 tonne ha^{-1} respectively. For the soil and crop evaluated in this study the maximum recommended chicken manure rate is 10-12.5 t ha^{-1} and in organic systems care is required to ensure chicken manure is not under or over applied.

Soil organic matter, total N, available P, exchangeable K, extractable Cu and Zn increased substantially with chicken manure application giving higher yield (Fig. 7.21). Total N and total K concentrations in plants were highest at the application of 10 and 12 tons ha^{-1} of chicken manure while total P was generally high in all treatments ranging from 0.23% to 0.45 %. Interestingly, though the application of 20 tons ha^{-1} of chicken manure enhanced the availability of N, P, K, and micronutrients (eg. Cu and Zn), optimum yield was attained at the application rate of 5 -10 tons ha^{-1}.

The postharvest qualities of two genotypes of eggplant was evaluated in response to increasing rates of chicken manure. The total soluble solids, pH and titratable acidity of eggplant were not affected by chicken manure application rate (Table 7.18). The effects of chicken manure application at about 600 g plant^{-1} gave the highest EC and vitamin C content. Ascorbic acid content and electrical conductivity both declined at chicken manure rates greater than 800 g plant^{-1} (10 t ha^{-1}). Cultivar Casino had a higher titratable acidity, total soluble solids and ascorbic acid values than cultivar Morena, but, lower pH, oxidation-reduction potential and electrical conductivity. The higher pH observed in cv. Morena fruits is likely related to its lower vitamin C concentration and lower titratable acidity.

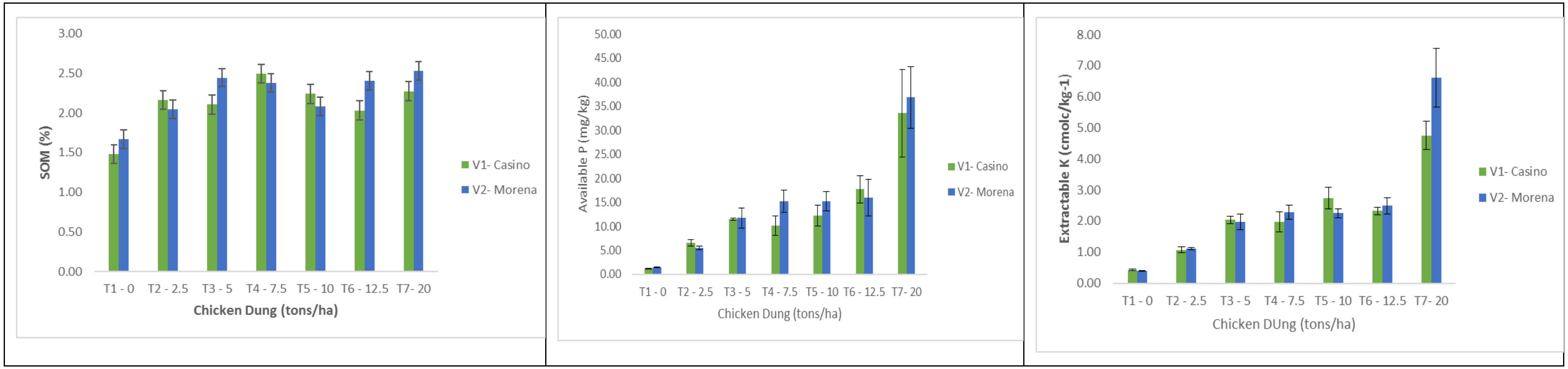


Figure 7.21. Soil organic matter (%), available P and extractable K in soil taken from a pot experiment a pot evaluating the effects of chicken manure rate (0-20 t ha^{-1} equivalent) on eggplant growth conducted at Leyte The Philippines.

Table 7.18. Effects of chicken manure (CM) application rate (0-1,600 g plant^{-1}) on eggplant (cvs Casino and Morena) fruit quality in a pot experiment conducted at Leyte Philippines.

CM rate (g plant^{-1})	EC (µS)	ORP (mV)	pH	TA (N)	TSS (brix)	Vit. C (% Asc)
Control	1727ab	-0.20b	5.17	0.0021	2.93	0.135ab
200	1802ab	0.35b	5.23	0.0021	2.65	0.155a
400	1798ab	0.90a	5.26	0.0021	2.40	0.160a
600	1838a	0.35b	5.28	0.0024	2.57	0.160a
800	1834a	0.40b	5.29	0.0026	2.80	0.135ab
1000	1629b	-0.15b	5.28	0.0022	2.65	0.105b
1600	1699ab	-1.25b	5.36	0.0016	2.78	0.105b
C.V. (%)	0.9	3.2	0.8	14.5	3.3	14.9
Genotypes						
Casino	1717b	-0.14b	5.21b	0.0029a	2.78a	0.141a
Morena	1806a	0.26a	5.32a	0.0014b	2.59b	0.131b
C.V. (%)	0.6	2.7	0.9	15.6	3.3	14.6

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.
EC = electrical conductivity in microSiemens
ORP = oxidation-reduction potential in millivolts
TA = titratable acidity expressed in Normality
TSS = total soluble solids in parts per million
Vit. C = vitamin C in percent ascorbic acid

Excessive application rates of chicken manure not only reduced eggplant fruit yield but also reduced fruit quality particularly vitamin C concentration and EC. The most cost-effective application rate of chicken manure was 400 g plant^{-1} (5 t ha^{-1}). Ascorbic acid content and electrical conductivity were enhanced by the application of chicken manure which declined beyond 800 g plant^{-1} (10 t ha^{-1}) particularly for ascorbic acid in cv. Casino and EC in cv. Morena. There was a large difference in fruit quality traits between varieties indicating a strong genetic influence. The data obtained in this experiment was specific for a particular amendment (chicken manure) which is the dominant form of amendment used in Philippine organic agriculture. Further research is required to identify variability in batch responses and to evaluate the response in other key vegetables (sweet pepper, cabbage, and tomato) and under other agro-climatic conditions. The effects of other sources of amendments (eg. manures, vermicomposts etc.) should be evaluated over a range of vegetable crop species.

7.3 Nitrogen response experiments

Eggplant response to N rate

In the absence of N application (0 kg N ha^{-1}), time to first flowering and harvest was delayed compared with all treatments receiving N application (50-300 kg N ha^{-1}) (Table 7.19). Plant height at first flower and final harvest, was also substantially reduced in the 0 kg N ha^{-1} treatment compared with all treatments receiving N application (50-300 kg N ha^{-1}), across which there was no treatment effect. The earliest flowering and time to first harvest occurred at an N application rate of 50-150 kg N ha^{-1} indicating that a rate of 50-150 kg N ha^{-1} was sufficient to meet flowering and reproductive demand. Though plant height is acknowledged as a key growth parameter influenced by fertilization, in this study there was no significant difference in plant height with increasing level of N between 50 to 300 kg N ha^{-1}. Cultivar Morena was harvested one day earlier than Casino and was consistently taller than Casino over the cropping cycle.

Table 7.19. Effects of N rate (0-300 kg ha^{-1}) on the time to first flower initiation and first harvest and on plant height at first flowering and final harvest of eggplant in a pot experiment conducted at Leyte Philippines.

N rate (kg ha^{-1})	Time to 1st flowering (DAT)	Time to 1st harvest (DAT)	Plant Height 1st Flowering (cm)^{NS}	Plant Height Final Harvest (cm)
0 (Control)	43.1 a	63.8 a	34.4 b	83.7 b
50	34.7 d	51.0 c	46.9 a	109.3 a
100	35.4 cd	52.1 bc	45.2 a	108.1 a
150	34.7 cd	52.8 bc	46.9 a	112.8 a
200	36.8 bc	53.5 b	44.8 a	107.5 a
250	37.8 b	52.5 bc	45.3 a	110.3 a
300	38.2 b	53.8 b	46.1 a	105.4 a
C.V. (%)	3.4	2.4	6.9	5.9
Genotypes				
Casino	37.3	54.7 a	44.1	99.7 b
Morena	37.2	53.7 b	44.4	110.9 a
C.V. (%)	3.3	5.3	6.1	6.0

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.

The yield data for the two eggplant cultivars over N rate are presented in Table 7.20. Application of 100-300 kg N ha^{-1} produced the greatest number, heaviest, and biggest fruits, which consequently gave the highest total yield. However, numerically speaking, the optimum yield of eggplant can be obtained at an application rate of about 150 kg N ha^{-1}. The marketable weight per plant was 10% greater in Morena ($p<0.05$) (Table 7.20) than cv. Casino, but total yield was not significantly different between the cultivars ($p<0.05$) though the yield value for cv. Morena was about 10% greater than Casino. The application of N at an appropriate rate is essential for optimising yield in eggplant production.

Table 7.21 shows the pigment composition across N application rates and the two eggplant cultivars. With a progressive increase in N application from 0-250 kg N ha^{-1}, chlorophyll A concentration and total carotenoid concentration increased in the harvested fruit, both reaching a maximum at 250 kg N ha^{-1}. With an increase in N rate from 250 to 300 kg N ha^{-1} both chlorophyll A concentration and total carotenoid concentration declined substantially to a value similar to, but lower than, that in the 0 kg N ha^{-1} treatment (Table 7.21). Between the N rates of 0 to 250 kg ha^{-1} the relationship between both chlorophyll A concentration and total carotenoid concentration with N application rate was strongly linear (Fig. 7.22). Chlorophyll A concentration was strongly correlated with total carotenoid concentration (Fig. 7.22) but there was no correlation between total carotenoid concentration and fruit yield. Chlorophyll is essential in the photosynthetic activity of the plant not only for its vegetative development but gives added value to the appearance and visual quality index of the harvested fruit. Progressive increases in N application rate from 0 to 250 kg N ha^{-1} significantly enhanced the total carotenoid content of the harvested fruit of eggplant but with a further increase in N application to 300 kg N ha^{-1} carotenoid concentration declined. Cultivar Morena had higher chlorophyll A and total carotenoid content ($p<0.05$) than cv. Casino which confirms the desirable fruit colouration (deeper colour) in cv. Morena. Cultivar Morena is of better quality not only in appearance but also in vitamin A both of which were enhanced by increasing N application.

Table 7.20. Effects of N rate (0-300 kg ha^{-1}) on mean fruit diameter (cm), marketable fruit number per plant (Mkt No.), marketable fruit weight per plant (Mkt Wt.) and marketable fruit yield (Mkt Yld) of eggplant grown in a pot experiment conducted at Leyte Philippines.

N rate (kg ha^{-1})	Fruit Diameter (cm)	Mkt No. (fruit plant^{-1})	Mkt Wt. (kg plant^{-1})	Mkt Yld (t ha^{-1})
0 (Control)	3.1 b	5.4 c	0.42 c	9.6 c
50	3.4 a	11.1 b	0.95 b	23.5 b
100	3.4 a	13.0 ab	1.12 ab	26.2 ab
150	3.4 ab	15.6 a	1.32 a	31.5 a
200	3.4 a	14.5 a	1.25 a	29.2 ab
250	3.5 a	14.2 a	1.22 ab	28.3 ab
300	3.3 ab	13.9 ab	1.17 ab	27.9 ab
C.V. (%)	3.7	12.7	12.6	12.2
Genotypes				
Casino	3.4 a	11.6	0.97 b	23.7
Morena	3.3 b	13.5	1.16 a	26.6
C.V. (%)	4.3	11.4	12.9	12.1

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD

The free radical scavenging activity (FRSA) and total dissolved solids (TDS) in eggplant fruit were not affected by N application rate (Table 7.22) though both traits differed across cultivars. Cultivar Casino exhibited a higher free radical scavenging activity than Morena ($p<0.05$) but had a lower TDS (Table 7.22). The effect of N application rate on the oxidation-reduction potential of eggplant fruit was significant but the trend was not consistent with progressive increases in N rate and hence not explicable. Cultivar Morena gave significantly higher TDS potentially indicating a greater ability to absorb minerals and nutrients from the soil and mobilise photosynthates into its fruit. The electrical conductivity, pH, titratable acidity and vitamin C content of eggplant fruit were not affected by N application rate and cultivar (data not presented). Judicious application of N fertiliser to attain highest yields gave the best postharvest qualities in eggplant fruit. The variation in postharvest qualities between the two cultivars would greatly influence their utilization, processing, and preparations as a fresh food commodity.

Table 7.21. Effects of N rate (0-300 kg ha^{-1}) on eggplant (cvs Casino and Morena) fruit quality in a pot experiment conducted at Leyte Philippines.

N rate (kg ha^{-1})	Chlorophyll A (mg kg^{-1})	Chlorophyll B (mg kg^{-1})^{ns}	Total Carotenoids (mg kg^{-1})
0 (Control)	3.59 bc	1.57	1.87 bc
50	3.67 bc	1.55	1.89 bc
100	3.81 abc	1.58	1.92 bc
150	4.30 ab	1.75	2.14 ab
200	4.20 abc	1.60	2.17 ab
250	4.55 a	1.63	2.28 a
300	3.40 c	1.36	1.71 c
C.V. (%)	13.1	15.2	4.7
Genotypes			
Casino	3.70 b	1.56	1.88 b
Morena	4.17 a	1.60	2.12 a
C.V. (%)	11.6	14.9	3.7

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD

Table 7.22. Effects of N rate (0-300 kg ha^{-1}) on eggplant (cvs Casino and Morena) fruit quality, free radical scavenging activity (FRSA), oxidation reduction potential (ORP) and total dissolved solids (TDS) in a pot experiment conducted at Leyte Philippines.

N rate (kg ha^{-1})	FRSA (μmolTE g^{-1})	ORP (mV)	TDS (mg kg^{-1})
0 (Control)	24.9	0.55 abc	628
50	25.5	0.14 d	626
100	25.9	0.31 bcd	652
150	25.7	0.48 abcd	623
200	25.4	0.21 cd	627
250	26.7	0.84 a	630
300	24.4	0.59 ab	600
C.V. (%)	6.5	23.1	2.8
Genotypes			
Casino	26.8 a	0.51	590 b
Morena	24.2 b	0.38	663 a
C.V. (%)	6.3	17.9	2.2

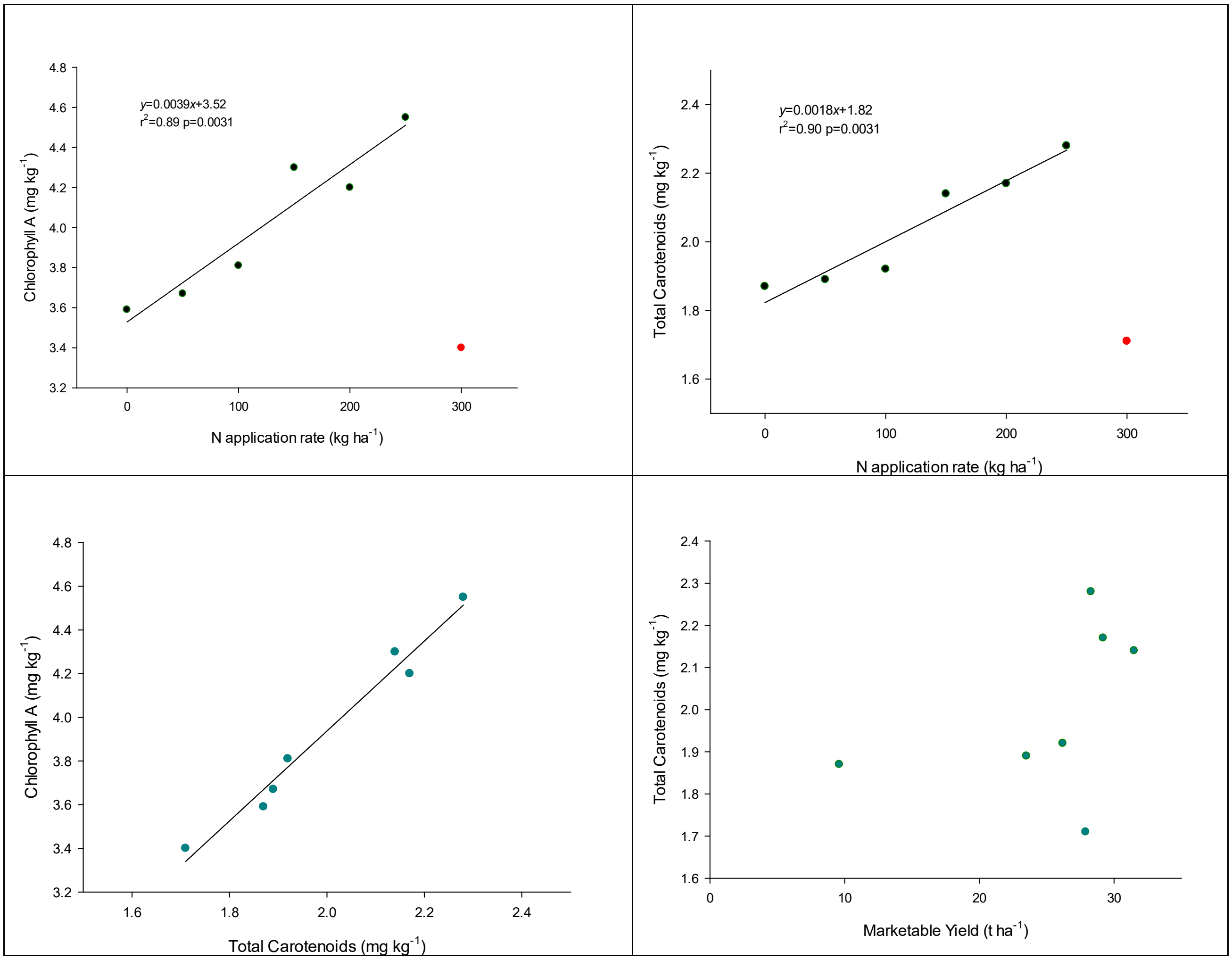


Figure 7.22 Relationship between chlorophyll A and N application rate (top left) and total carotenoids and N application rate (top right), chlorophyll A and total carotenoids (lower left) and total carotenoids and yield (lower right) in a pot experiment evaluating the effects of N rate (0-300 kg ha^{-1}) on eggplant fruit quality conducted at Leyte Philippines.

Sweet pepper response to N rate

The growth response of sweet pepper (cvs Emperor and Sultan) to N application rate in the wet and dry seasons is presented in Table 7.23. The number of days from transplanting to first harvest was shorter during the dry season and was enhanced by N fertilization but there was no significant difference between genotypes. The application of 100 kg N ha^{-1} during the wet season gave the shortest time from transplanting to first harvest, particularly with cv. Sultan. At flowering, sweet pepper plants were taller during the wet season irrespective of cultivar. The plants receiving 250 and 200 kg N ha^{-1} were tallest in both the wet and dry seasons and similar responses in sweet pepper are reported (Bar-Tal *et al*., 2001; Bowen and Frey, 2002; Aminifard *et al.,* 2012). Plant height is an important index of plant vigour, which is greatly affected by soil nutrient supply (Aminifard *et al*., 2012). Plants in the treatment with 300 kg N ha^{-1} had the longest time to first harvest and had the shortest plants. Stefanelli *et al*., (2010) identified that high rates of N lead to poor fruit set and negative effects on the secondary metabolites.

Data for fruit number per plant and dry matter biomass per plant across N rates is presented in Table 7.24. Cultivar Sultan had a greater number of marketable fruits per plant, total fruit weight, and plant biomass during the wet season cropping (Table 7.24) compared with cv. Emperor. The 0 kg N ha^{-1} treatment had lower fruit number and foliage biomass than other treatments but there was essentially no significant differences in fruit number or foliage biomass at N rates from 50 to 300 kg ha^{-1}. Fitted curvilinear regression showed that the optimal N application rate to achieve maximum fruit set in the wet season was 150 kg N ha^{-1} whilst in the dry season it was achieved at 250-300 kg N ha^{-1} (Fig. 7.23). The highest average fruit yield per plant and fruit yield (t ha^{-1}) were recorded at 50–200 kg N ha^{-1} during the wet season (Table 7.25). In the dry season an application of 300 kg N ha^{-1} resulted in the highest average fruit yield per plant and fruit yield (t ha^{-1}); though these were comparable with other treatments.

Table 7.23. Effects of N rate (0-300 kg ha^{-1}) on the time to first flower initiation and first harvest and on plant height at first flowering, first harvest and final harvest of sweet pepper (cultivars Emperor and Sultan) in field trials during the wet season (WS) and dry season (DS) conducted at Leyte Philippines.

N rate (kg ha^{-1})	Time to 1st flowering (DAT)		Time to 1st harvest (DAT)		Plant Height 1st Flowering (cm)		Plant Height 1st Harvest (cm)		Plant Height Final Harvest (cm)	
	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
0 (Control)	24.9	22.6	62.2 bcd	57.6 a	40.8 bc	27.0 ab	57.4 bc	39.7 b	67.0 b	52.2 b
50	23.8	22.0	61.8 bcd	56.1 b	40.3 c	29.2 ab	58.1 bc	48.0 a	67.9 ab	60.2 a
100	21.3	22.8	61.1 d	56.4 b	44.0 abc	27.5 ab	62.7 a	44.6 ab	71.8 a	57.0 a
150	21.9	23.0	61.2 cd	56.4 b	44.8 ab	28.6 ab	59.6 ab	46.3 a	69.2 ab	58.5 a
200	20.9	23.1	66.7 abc	56.3 b	45.0 ab	29.5 a	56.9 bc	48.0 a	66.6 b	60.7 a
250	22.4	22.5	67.3 ab	55.9 b	45.7 a	28.4 ab	57.6 bc	47.0 a	67.7 ab	59.4 a
300	21.8	23.2	68.2 a	56.0 b	42.7 abc	26.1 b	55.4 c	47.1 a	65.4 b	60.0 a
C.V. (%)	12.3	6.7	5.3	0.8	6.1	8.7	4.3	6.7	3.8	4.9
Genotypes										
Emperor	22.6	22.8	64.8 a	56.5	43.0	27.7	57.1 b	44.9 b	67.3	56.7 b
Sultan	22.2	22.7	63.3 b	56.3	43.6	28.3	59.4 a	46.7 a	68.6	59.9 a
C.V. (%)	11.4	5.8	4.2	0.7	7.7	6.6	6.8	6.8	5.8	5.1
Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.										

The relationships between N application rate, and, fruit number per plant, plant biomass, plant fruit weight and fruit yield per ha in the wet season were not as strong as that in the dry season presumably due to the incidence of bacterial leaf spot during the wet season and subsequent variability (Fig. 7.23). For the dry season, the relationships between N application rate, and, fruit number per plant, plant biomass, plant fruit weight and fruit yield per ha were strong and generally highlighted that growth responses in these parameters were maximised at about 250-300 kg N ha^{-1}. The marked effect of N on yield might be due to the cumulative stimulating effect of N on the vegetative growth, the strength of which forms the basis for flowering and fruiting (Aminifard *et al.,* 2012). Pepper fruits accumulate 40% to 64% of total plant N uptake (Olsen *et al.,* 1993).

Table 7.24. Effects of N rate (0-300 kg ha^{-1}) on mean fruit diameter (cm), marketable, non-marketable and total fruit number per plan and foliage biomass of sweet pepper (cvs Emperor and Sultan) grown in a field experiment conducted at Leyte Philippines in the Wet season (WS) and Dry Season (DS).

N rate (kg ha^{-1})	Number of fruits per plant						Foliage Biomass	
	Marketable		Non-marketable		Total			
	WS	DS	WS	DS	WS	DS	WS	DS
0 (Control)	8.0 b	9.6 c	1.4 b	1.4 b	9.4 b	11.0 b	16.1 b	8.2 c
50	14.4 a	21.0 ab	3.9 a	3.1 a	18.3 a	24.1 a	24.4 a	14.0 bc
100	14.3 a	19.9 b	3.0 ab	2.7 ab	17.3 a	22.6 a	22.4 ab	19.0 ab
150	15.1 a	21.0 ab	3.6 ab	2.0 ab	18.8 a	23.0 a	19.4 ab	22.7 a
200	13.3 a	23.4 ab	2.9 ab	3.1 a	16.1 a	26.5 a	16.5 b	23.8 a
250	11.6 ab	23.6 ab	3.3 ab	3.2 a	14.9 a	26.8 a	17.6 ab	23.6 a
300	11.5 ab	24.7 a	2.5 ab	3.2 a	14.0 ab	27.9 a	22.0 ab	22.1 ab
C.V. (%)	19.7	17.4	46.5	34.3	21.3	18.5	21.0	26.7
Genotypes								
Emperor	11.0 b	20.1	2.9	2.7	14.0 b	22.8	15.9 b	19.3
Sultan	14.1 a	20.8	2.9	2.6	17.1 a	23.4	23.6 a	18.8
C.V. (%)	19.2	9.2	42.5	30.0	19.4	10.1	23.0	23.2

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.

Sweet pepper cv. Emperor had significantly higher free radical scavenging activity compared with cv. Sultan in both wet and dry seasons. Free radical scavenging activity progressively increased from an N application rate of 0 kg N ha^{-1} and peaked at 150 kg N ha^{-1} above which it progressively declined to 300 kg N ha^{-1} (Fig. 7.24). The response in free radical scavenging activity to N application rate were the same for both wet and dry season.

Total carotenoid content increased with increasing N rate in both the wet and dry season though the effect of N on carotenoid concentration was more pronounced in dry season production compared with wet season production (Fig. 7.24). The data shows that optimisation of N management can be used to improve vegetable (sweet pepper) quality. Sweet pepper is an excellent source of bioactive phytochemicals such as vitamin C, carotenoids and phenolic compounds which define its quality and antioxidant capacity (Flores *et al*., 2004). Carotenoids, particularly lycopene, are powerful natural antioxidants recognised as beneficial for preventing a broad range of human diseases (Byers and Perry, 1992). These antioxidants are effective free radical scavengers and may be important for the prevention of age related macular degeneration (Howard *et al.,* 2000). There was a well-defined seasonal effect on the ORP for the sweet peppers. Across N treatments in the dry season there was essentially no difference in ORP but in contrast the ORP values in the wet season were lower and tended to be lowest at an N rate of 100-200 kg N ha^{-1} (Fig. 7.24). In the wet season application of N outside this range increased ORP values. This data highlights that differences in a range of food quality traits can relate to environmental, genetic and agronomic factors.

Figure 7.23. Relationship between total fruit number per plant and N application rate (top left), Foliage dry mass and N application rate (top right), Total fruit mass per plant and N application rate (lower left) and fruit yield and N application rate (lower right) in field experiments evaluating the effects of N rate (0-300 kg ha^{-1}) in wet and dry seasons on sweet pepper conducted at Leyte Philippines.

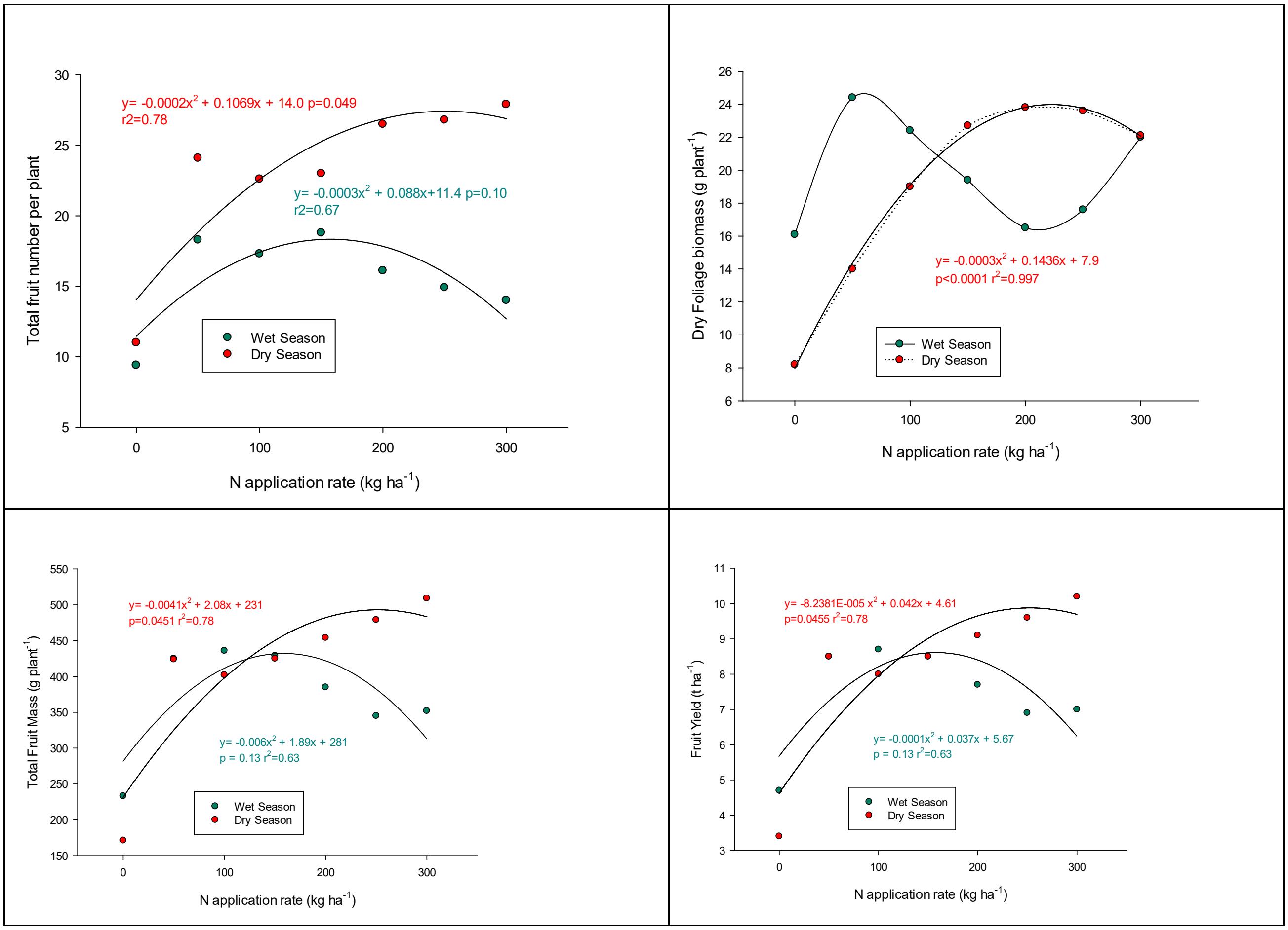


Table 7.25. Effects of N rate (0-300 kg ha^{-1}) on marketable, non-marketable and total fruit weight per plant and marketable fruit yield (Mkt Yld) of sweet pepper (cvs Emperor and Sultan) grown in field experiments in the wet season (WS) and dry season (DS) conducted at Leyte Philippines.

N rate (kg ha^{-1})	Weight of fruit per plant						Mkt Yld (t ha^{-1})	
	Marketable		Non-marketable		Total			
	WS	DS	WS	DS	WS	DS	WS	DS
0 (Control)	218 b	157 b	15 b	14 b	233 b	171 b	4.7 b	3.4 b
50	377 a	383 a	48 a	41 a	425 a	424 a	8.5 a	8.5 a
100	392 a	371 a	44 a	32 ab	436 a	402 a	8.7 a	8.0 a
150	379 a	397 a	50 a	28 ab	429 a	425 a	8.5 a	8.5 a
200	350 a	414 a	35 a	40 a	385 a	454 a	7.7 a	9.1 a
250	304 ab	439 a	41 a	40 a	345 ab	479 a	6.9 ab	9.6 a
300	310 ab	472 a	42 a	37 a	352 ab	509 a	7.0 ab	10.2 a
C.V. (%)	22.2	18.3	28.5	37.8	20.5	13.6	20.5	18.6
Genotypes								
Emperor	280 b	349 b	39	32	319 b	381 b	6.4 b	7.6 b
Sultan	385 a	403 a	40	35	425 a	438 a	8.5 a	8.8 a
C.V. (%)	17.6	13.8	38.5	33.9	16.9	14.0	16.9	14.0

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.

Table 7.26. Effects of N rate (0-300 kg ha^{-1}) on sweet pepper (cvs Emperor and Sultan) fruit quality including, free radical scavenging activity (FRSA), oxidation reduction potential (ORP), and total carotenoids in field experiments conducted in the wet season (WS) and dry season (DS) at Leyte Philippines.

N rate (kg ha^{-1})	FRSA (µmol TE g^{-1})		ORP (mV)		Total Carotenoids (mg kg^{-1})	
	WS	DS	WS	DS	WS	DS
0 (Control)	28.8 b	30.5 e	0.10 a	0.60 ab	0.63 c	0.64 c
50	29.0 b	31.4 e	-0.33 ab	0.60 ab	0.73 bc	0.73 bc
100	37.6 ab	40.9 bc	-0.61 b	0.48 b	0.79 abc	1.00 ab
150	52.6 a	53.9 a	-0.55 b	0.52 b	0.99 a	0.98 abc
200	42.3 ab	43.3 b	-0.65 b	0.60 ab	0.83 abc	1.05 ab
250	37.2 ab	37.7 cd	0.06 a	0.50 b	0.93 ab	1.11 a
300	35.0 ab	35.5 de	-0.01 a	0.75 a	0.77 abc	1.04 ab
C.V. (%)	5.8	8.0	13.3	14.4	6.8	22.4
Genotypes						
Emperor	48.6 a	47.2 a	-0.35	0.64 a	0.72 b	0.74 b
Sultan	26.4 b	30.8 b	-0.22	0.52 b	0.89 a	1.13 a
C.V. (%)	4.9	30.9	21.5	12.7	6.7	24.4

Treatment means with the same letter are not significantly different at 5 % level based on Tukey's HSD.

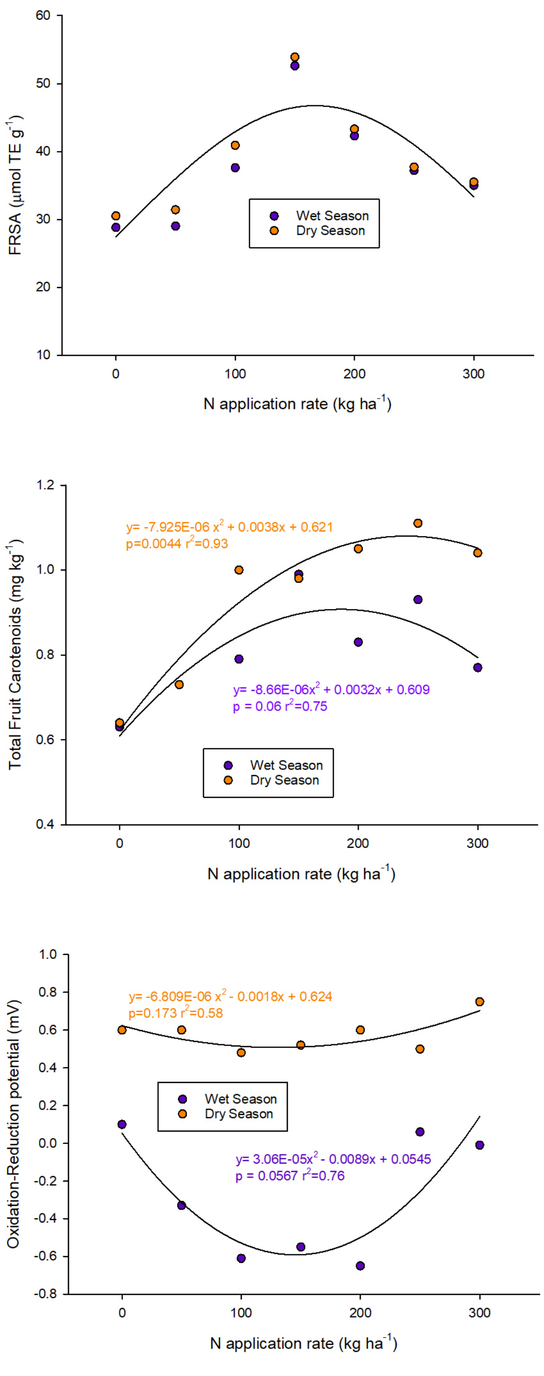


Figure 7.24. Relationship between N application rate (0-300 kg ha^{-1}) and sweet pepper quality traits including, free radical scavenging activity (FRSA), oxidation reduction potential (ORP), and total carotenoids in field experiments conducted in the wet season (WS) and dry season (DS) at Leyte Philippines.

Tomato response to N application

For tomato, there was no difference in days to flowering, plant height at harvest, stem diameter and percentage plant survival across N treatments (0-250 kg N ha^{-1}) in the first and second cropping (data not presented). An N application of 150 kg N ha^{-1} produced the highest dry matter yield of 176 g plant^{-1} (Table 7.27). The heaviest marketable fruits were recorded in the second experiment where 150 kg N ha^{-1} was added (46.9 g fruit^{-1}) (Table 7.28). The highest fruit yield was obtained at 150 kg N ha^{-1} which also gave the largest and greatest number of fruits in both the first and second cropping (Table 7.28). Furthermore, at this rate, mean fruit weight and fruit diameter were greatest in both the first and second seasons. This result is different from that of Warner et al, (2004) who identify that fruit size was not influenced by N fertilization. Large fruit weight and size in combination with marketable fruits per plant is a key contributing factor to maximising yield per hectare. In the 0 kg N ha^{-1} treatment the fruit were substantially smaller and lighter.

An application of N at 250 kg ha^{-1} gave a higher non-marketable tomato yield (data not presented) suggesting that N application rates greater than 250 kg N ha^{-1} are not likely to increase tomato yield resulting in excessive fertiliser application and potential environmental loss. Soil nutrients (particularly nitrate) that are not immediately taken up present a high risk of being lost through leaching and denitrification.

The highest incidence of disease was recorded at N application rates of 100-200 kg N ha^{-1} at 60 DAT during the first cropping and plots not receiving N fertiliser had lowest incidence. However, this effect was not evident by the first harvest (data not presented). The trend suggested that excessive N application could influence the expression of diseases in tomato. Parisi et al. (2004) found that excess N supply can lead to greater virus incidence, though in this study susceptibility to TYLCV was more related to cultivar than crop nutrition. Nitrogen fertilization at 150 kg N ha^{-1} is recommended for increasing the yield and fruit quality of tomato.

Table 7.27. Effects of N rate (0-250 kg ha^{-1}) on tomato (cvs Harabas and ATVO1173) dry matter yield in a field experiment conducted at Claveria, Misamis Oriental 2016 Philippines.

N rate** (kg ha^{-1})	DRY MATTER YIELD (g/plant)
0 (Control)	142 cd
50	153 bc
100	162 b
150	176 a
200	125 e
250	134 de
Varieties (B)**	
Harabas (Check)	103 b
AVTO1173	194 a

* Indicates treatment difference are significant at p ≤0.05

** Indicates treatment difference are significant at p ≤0.01

Table 7.28. Effects of N rate (0-250 kg ha^{-1}) on tomato (cvs Harabas and ATVO1173) fruit weight and diameter, and, yield in 2 experiments (2016 and 2017) conducted at Claveria, Misamis Oriental Philippines.

N rate (kg ha^{-1})	First planting				Second planting		
	Fruit Wt. (g)	Fruit Diameter (cm)	YIELD (t ha^{-1})	DM Yield (g plant^{-1})	Fruit Wt. (g)	Fruit Diameter (cm)	YIELD (t ha^{-1})
0 (Control)	34.4 b	3.5 c	9.8 c	142.4 cd	43.5 b	4 b	21.2 d
50	36.5 b	3.6 bc	13 b	153.5 bc	43.2 b	4.1 ab	26.4 b
100	36.2 b	3.8 b	13.4 ab	162.1 b	47.5 ab	4.2 a	26.3 b
150	36.5 ab	4.2 a	14.4 a	176 a	49.6 a	4.2 a	28.1 a
200	39.1 a	3.8 b	13.7 ab	125.1 e	47 ab	4.1 ab	26.7 b
250	35.9 b	3.5 c	13.9 ab	132.6 de	47.1 ab	4 ab	23.6 c
F-test significance	**	**	**		**	*	**
Varieties (B)							
Harabas	35.6 b	3.3 b	12.7 b	102.9 b	49.3 a	4.3 a	29.6 a
AVTO 1173	37.2 a	4.2 a	13.4 a	194.4 a	43.3 b	3.9 b	21.1 b
F-test significance	*	**	**	**	**	**	**

* Indicates treatment difference are significant at p ≤0.05
** Indicates treatment difference are significant at p ≤0.01

Cabbage response to N rate

Application of N at 200 and 250kg kg N ha^{-1} produced the largest heads, both for polar and equatorial dimensions, during the first cropping (data not presented). In both the first and second cropping the number of leaves per plant increased progressively with increasing N application rate to a maximum of 300 kg N ha^{-1} (Table 7.29). The result indicated an increasing trend of leaf count value in proportion to the amount of N; the higher the N application rate the greater the number of leaves. Cultivar Resist Crown consistently produced heads with a greater number of leaves and head dimensions than cv. Kex-734 (Table 7.29). Across cultivars the highest marketable yield for the first and second cropping was at 150-200 kg N ha^{-1} (Table 7.30) with the lowest marketable yield being recorded in the 0 kg N ha^{-1}. Cultivar Resist Crown produced the highest marketable cabbage head weight in both cropping periods (Table 7.30) and the highest yield in the second cropping. The proportion of marketable heads was strongly positively correlated with N application rate (Fig. 7.25). The fitting of a quadratic regression function identified that application of N at 150-200 kg N ha^{-1} gave the maximum proportion of marketable heads (about 65-75%), particularly in the first cropping cycle. At N rates outside this range (higher and lower) the proportion of marketable heads was reduced (50-65%). The optimal N rate of 200 kg N ha-1 gave the lowest non-marketable yield; Hasan (2010) identify that increasing the N rate does not greatly impact marketable yield. However, other authors indicate that excessive N generally leads to excessive vegetative growth, often to the detriment of root and head development (Stefanelli et al, 2010).

Table 7.29. Effects of N rate (0-300 kg ha^{-1}) on cabbage (cvs Resist Crown and KEX-734) leaf number in 2 experiments conducted at Claveria, Misamis Oriental Philippines.

N rate (kg ha^{-1})	Number of leaves per plant	
	1st cropping	2nd cropping
0	83.62 e	34.37 b
50	84.37 e	34.43 b
100	86.00 d	33.37 b
150	88.50 c	39.75 a
200	91.37 b	38.87 a
250	92.25 b	39.75 a
300	94.25 a	39.06 a
F-test	**	**
Varieties (B)		
Resist Crown	92.50 a	42.17 a
KEX - 734	84.75 b	32.00 b
F-test	**	**
A x B		
F-test	ns	*
C.V. (%)		
(A)	0.97	4.19
(B)	1.23	5.54

* Indicates treatment difference are significant at $p \leq 0.05$

** Indicates treatment difference are significant at $p \leq 0.01$

Table 7.30. Effects of N rate (0-300 kg ha^{-1}) on cabbage (cvs Resist Crown and KEX-734) mean marketable (Mkt_Hd) and non-marketable (Non-Mkt_Hd) head weight and marketable yield (Mkt_Yld) in 2 experiments conducted at Claveria, Misamis Oriental Philippines

N rate (kg ha^{-1})	1st Cropping Mkt_Hd (kg)	Non-Mkt_Hd (kg)	Mkt_Yld (t ha^{-1})	2nd Cropping Mkt_Hd (kg)	Non-Mkt_Hd (kg)	Mkt_Yld (t ha^{-1})
0	0.71 d	0.61 a	31.8 d	0.43 d	0.40 a	19.6 d
50	0.73 d	0.51 b	33.1 d	0.48 c	0.27 b	21.6 c
100	0.78 c	0.47 c	35.4 cd	0.46 c	0.21 c	21.0 c
150	1.03 a	0.42 d	47.4 a	0.56 a	0.18 d	23.3 a
200	1.01 a	0.30 e	45.7 a	0.56 a	0.18 d	25.3 a
250	0.90 b	0.47 c	40.4 b	0.52 b	0.19 d	23.6 b
300	0.83 c	0.48 c	37.4 bc	0.52 b	0.21 c	23.6 b
F-test	**	**	**	**	**	**
Varieties (B)						
Resist Crown (Check)	0.87 a	0.50 a	38.94	0.57 a	0.19 b	25.66 a
KEX-734	0.84 b	0.43 b	38.58	0.44 b	0.27 a	20.03 b
F-test	**	**	ns	**	**	**

* Indicates treatment difference are significant at p ≤0.05
** Indicates treatment difference are significant at p ≤0.01

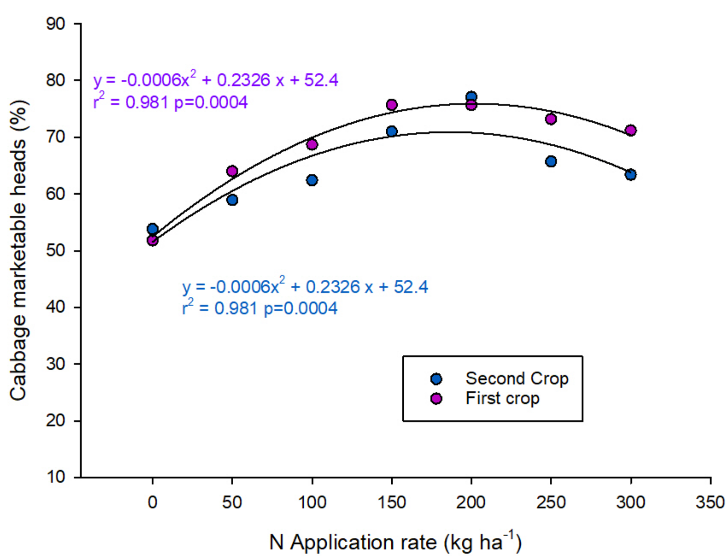


Figure 7.25. Cabbage yield response to N application rate (0-300 kg ha^{-1}) in two field experiments conducted at Claveria, Misamis Oriental Philippines.

Bunching onion response to N application

An experiment evaluated the effects of N rate (0-200 kg N ha^{-1}) on the growth and quality of 2 cultivars (Paragon and Zoolander) of Australian bunching onion (viz. Japanese bunching onion).

The fresh yield of bunching onion increased progressively with increasing N application rate to a maximum of 64.0 t ha^{-1} at 200 kg N ha^{-1} (Table 7.31). However, dry matter concentration of the foliage decreased with increasing N rate indicating the softness of product was improved with increasing N. Measurements of chroma and hue characteristics of the foliage showed that a deeper blue green colour (desired by the market) was obtained at the optimised N rate and UAV multispectral imaging also visually confirmed this (Fig. 7.26). The dry matter yield showed the same pattern of response to N application as the fresh yield data.

The standard application rate for farmers is about 120 kg N ha^{-1} and the yield at this N rate was about 15% less than the maximum recorded at 200 kg N ha^{-1}. Yield *per se* is not such a critical factor for bunching onion since over time even at the grower rate the marketable size will be achieved albeit it at a later date. The importance of optimising N application lies more in the visual quality of bunching onions. Application of higher N rates gave improved foliage colour (particularly hue) giving a bluer-green foliage that is more acceptable in the market. The chroma did not differ significantly between the 160 and 200 kg N ha^{-1} treatments however in the UAV imaging there appeared to be a visual difference (Fig. 7.26).

Table 7.31 Response of bunching bunching onion fresh yield, foliage dry matter concentration (DM%), dry matter yield and foliage chroma, hue and lightness across N application rates (0, 40, 80, 120, 160 and 200 kg ha^{-1}) in a field experiment at Queensland DAF Gatton Research Facility 2016.

N Rate (kg ha^{-1})	Fresh Yield		DM%		Dry Matter Yield		Chroma (C)		Hue (H)		Lightness (L)	
0	14.7	d	13.1	a	1.9	d	23.6	ab	130.8	cd	52.2	ab
40	24.5	d	12.1	b	2.9	c	25.8	a	128.8	d	53.4	a
80	38.1	c	12.0	b	4.5	b	25.7	a	129.3	d	51.6	b
120	53.5	b	9.5	c	5.0	ab	22.4	bc	132.2	bc	47.9	c
160	56.0	ab	9.0	cd	5.1	ab	20.7	cd	133.8	ab	45.4	d
200	64.0	a	8.8	d	5.6	a	19.6	d	135.1	a	44.9	d
F test												
Prob.	<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	
LSD (5%)	9.9		0.55		0.92		2.3		2.2		1.8	

There was an interaction between variety and N rate on foliage hue. Cultivar Paragon had a lower hue value than cv. Zoolander at the lowest N rate but this increased greatly with increasing N application rate. In contrast, the increase in hue for Zoolander was less pronounced with increasing N rate. This shows a differential effect of N application rate on foliage spectral characteristics in the different cultivars. The UAV imaging indicates that the form of N in this experiment had an effect on foliage colour. Bunching onion foliage colour appeared to be enhanced when a predominantly ammonium-N form was applied (Fig. 7.27).

The research has shown that different forms of N (ammonium, nitrate and urea) have differential effects on crop growth which appears to be influenced genetically since cultivars Paragon and Zoolander exhibited a differential response. The yield reductions can be in the order of 15% and importantly reduce vegetable product quality.

Table 7.32 Change in foliage hue with different N application rate (0, 40, 80, 120, 160 and 200 kg ha^{-1}) in 2 cultivars of bunching onion (cvs Paragon and Zoolander)

N Rate	Hue angle			
(kg ha^{-1})	Paragon		Zoolander	
0	128.2	ef	133.3	abcd
40	126.8	f	130.8	de
80	127.0	f	131.6	cd
120	132.2	bcd	132.1	bcd
160	133.5	abcd	134.1	abc
200	135.4	a	134.8	ab
F test Prob.	0.034			
LSD (5%)	3.132			

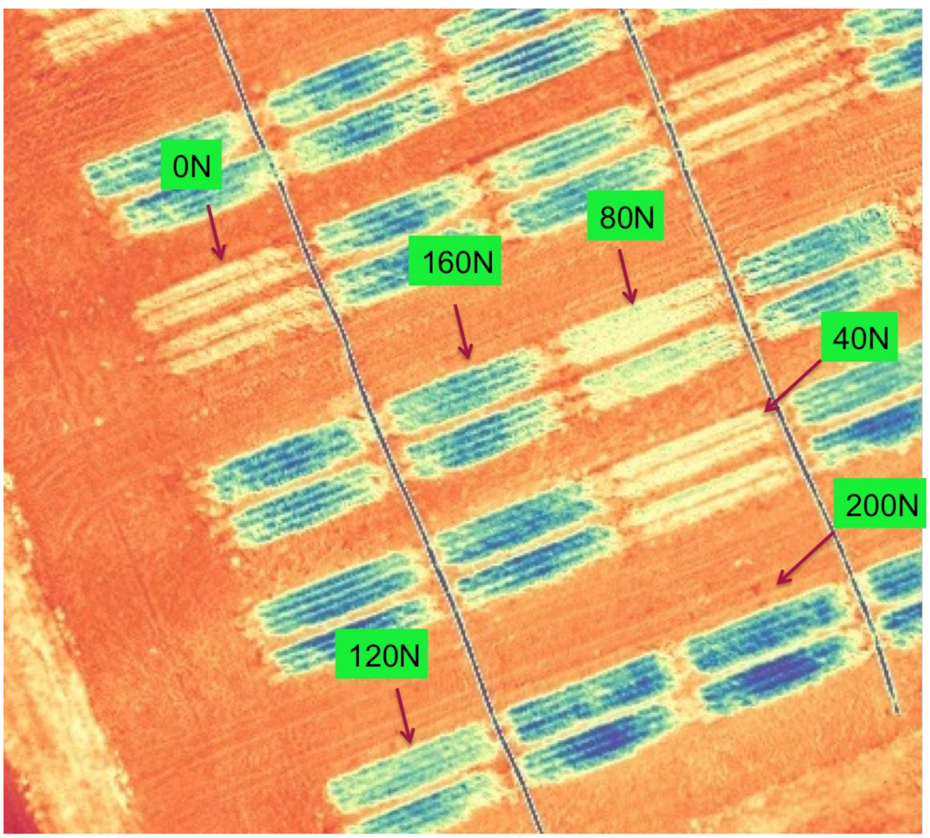


Figure 7.26 Spectral image taken from a UAV drone in an experiment evaluating the effects of nitrogen fertiliser rate on bunching onion growth (the plots are paired with 2 varieties Paragon and Zoolander).

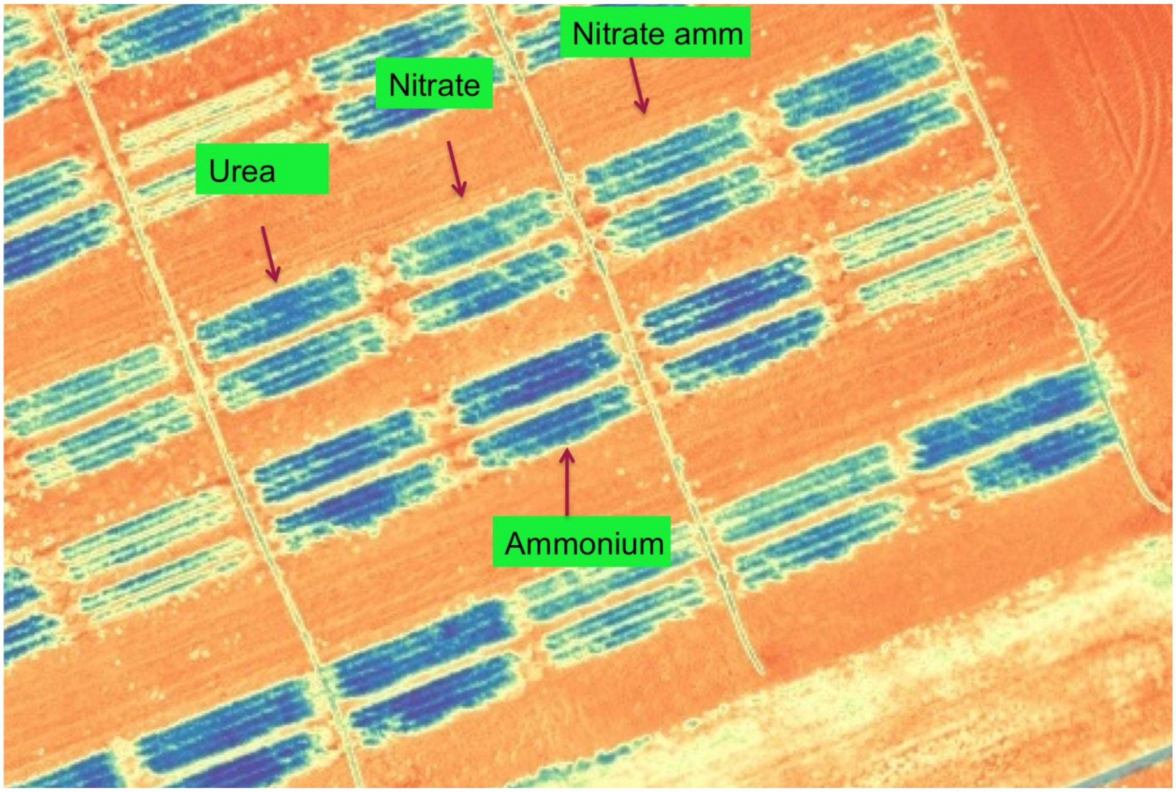


Figure 7.27 Spectral image taken from a UAV drone in an experiment evaluating the effects of nitrogen fertiliser rate on bunching onion growth (the plots are paired with 2 varieties Paragon and Zoolander).

7.4 Effects of Phosphorus biofertilisers and micronutrients on cabbage.

Phosphorus and MykoPlus effects on cabbage

A significant increase in fresh marketable head weight was obtained with increasing P application rates (Table 7.33). This effect was further enhanced with the addition of the microbial inoculant MykoPlus. The fresh weight of cabbage heads ranged from 0.11 kg head^{-1} in the control treatment to 0.92 kg head^{-1} obtained with the application of the highest P rate (44 kg P ha^{-1}) in combination and MykoPlus (Table 7.33). However, this was not significantly different from the head weight (0.80 kg head^{-1}) obtained with the application of 22 kg P ha^{-1} in combination with MykoPlus. The total plant fresh weight increased with increasing P application rate (Table 7.33) and the effect of P was enhanced when combined with MykoPlus (T_5) for which the total plant fresh weight was 1.46 kg plant^{-1} and in T_7 1.60 kg plant^{-1}.

Table 7.33. Effects of P rate (0, 22 and 44 kg ha^{-1}) and MykoPlus on cabbage plant head fresh weight (Hd_Fr_Wt), total plant fresh weight (kg plant^{-1}) (TotFrWt), wrapper leaf yield (WrLfYld), marketable head yield (MktHdYld), relative yield improvement to Control (RYI) and harvest index in an experiment conducted at Claveria, Misamis Oriental Philippines.

Treatment	Hd_Fr_Wt (kg plant^{-1}) **	TotFrWt (kg plant^{-1}) **	WrLfYld (t ha^{-1}) **	MktHdYld (t ha^{-1}) **	RYI	HARVEST INDEX **
Control (T_1)	0.11 d	0.27 d	8.2 d	6.0 d	0.0	0.39 c
0P(T_2)	0.27 c	0.63 c	17.2 cd	15.4 c	1.5	0.43 bc
0P+MykoPlus(T_3)	0.30 c	0.71 c	19.1 bc	16.9 c	1.8	0.42 bc
22P(T_4)	0.53 b	1.01 b	22.7 bc	29.5 b	3.9	0.52 abc
22P+MykoPlus(T_5)	0.80 a	1.46 a	24.6 bc	45.0 a	6.5	0.55 ab
44P (RRP) (T_6)	0.63 b	1.18 b	26.8 ab	35.5 b	4.9	0.54 ab
44P+MykoPlus(T_7)	0.92 a	1.60 a	35.5 a	51.7 a	7.6	0.58 a

In a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05)
RRP denotes recommended P application rate.

The yield of wrapper leaves was significantly affected by treatment (Table 7.33) and was greatest at the highest P rate (44 kg ha^{-1}) with MykoPlus. Application of N and K without P application increased marketable yield by 155% (Table 7.33) indicating that N and K are among the key nutrients limiting cabbage yield in the Jasaan clay. Progressive increases in P application from 0 to 22 to 44 kg P ha^{-1} gave substantial increases in marketable head yield (Table 7.33). Addition of 22 kg P ha^{-1} increased yield by 92% from 15.4 to 29.5 t ha^{-1} and yield was increased by about a further 50% (from 29.53 to 45.03 t ha^{-1}) with the addition of MykoPlus. The effect of MykoPlus in the absence of P application was not significant though the yield value was 10% higher. Increasing the P rate to 44 kg P ha^{-1} increased yield by 131% (from 15.4 to 35.5 t ha^{-1}) and when combined with MykoPlus yield increased by a further 46% (from 35.5 to 51.7 t ha^{-1}). The crop harvest index also increased with increasing P rate and improved slightly with the addition of MykoPlus (Table 7.33).

Results are consistent with the findings of Filho et al. (2013) on the effects of different P rates on 'Fuyutuyo' cabbage grown in a typical P-rich Oxisol. They observed that cabbage planted in highly weathered tropical soils are strongly responsive to P fertilization since P availability is limited in these acidic soils with high P fixation potential. Though net uptake of P was lower than that of N and K it remains a critical nutrient in acidic soils with high P fixation.

The use of microbial inoculants, such as MykoPlus which contains P-solubilizing bacteria, may have the potential to improve phosphate availability in tropical acidic soils (Anand et al., 2016), as shown in this trial. Importantly, this result has been obtained in a field trial, while most research evaluating P-solubilizers has been at the laboratory culture (petri dish), or glasshouse pot trial scale; the number of field trials is quite small. Unfortunately, there is no simple message from the field trials; some trials showed growth enhancement and/or increased P uptake, but there is large variation in the effectiveness of inoculation with P solubilising organisms (Gyaneshwar et al., 2002). Tandon (1987) undertook a review of this research, and while this report is now 30 years old, the conclusions he reached at that time are still applicable today. Tandon reported that inoculation resulted in 10 to 15% yield increases in 10 out of the 37 experiments he considered; in the remaining trials (70% of cases) there was no increase. Furthermore, many responses to biofertilizers are small. For example, a detailed field evaluation of the effect of solubilizers on maize growth (461 trials) showed positive responses in 80% of trials, but the yield increase ranged from 0.7 to 3.7 % (Leggett et al 2015). Thus the substantial response found here warrants further investigation.

In both the 30 DAT and at harvest samples, all treatments receiving P application tended to have higher tissue N concentrations than the control or the 0 kg P ha^{-1} treatments (Table 7.34). The P concentration in cabbage, both at 30 DAT and at harvest, was higher when P was applied in combination with MykoPlus to a maximum tissue concentration of 0.37%. The P requirement of cabbage increased with maturity as shown by higher P concentrations. The P concentration in the at harvest samples for the 0P+MykoPlus treatment (0.23%) was greater than that in the 0 P treatment ($p<0.05$) indicating that the Mykoplus facilitated P uptake and that the 10% difference in yield between these treatments is likely to be a real effect. Total K concentration was not significantly influenced by P rates and application of MykoPlus (data not presented).

Table 7.34. Effects of P rate (0, 22 and 44 kg ha^{-1}) and MykoPlus on cabbage N, P, and K tissue concentrations at 30 days after transplanting (DAT) and at harvest in an experiment conducted at Claveria, Misamis Oriental Philippines.

TREATMENTS	N (%)		P (%)	
	30 DAT **	HARVEST **	30 DAT **	HARVEST **
Control	1.38 c	1.54 c	0.11 c	0.13 d
0 P	1.48 bc	1.66 bc	0.11 c	0.15 d
0 P + MykoPlus	1.85 ab	1.96 ab	0.12 c	0.23 c
22 P	1.77 ab	1.92 ab	0.20 bc	0.26 c
22 P + MykoPlus	1.88 a	1.99 ab	0.23 ab	0.29 bc
44 P (RRP)	1.86 a	1.97 ab	0.28 ab	0.34 ab
44P + MykoPlus	1.90 a	2.07 a	0.33 a	0.37 a
Within a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05)				

Uptake of N, P, and K (kg ha^{-1}) at harvest was influenced by the application of increasing rates of phosphorus and MykoPlus (Fig. 7.28). Nitrogen uptake was highest with the application of 22 kg P ha^{-1} (50 kg P_2O_5 ha^{-1}) and 44 kg P ha^{-1} (100 kg P_2O_5 ha^{-1}) in combination with MykoPlus and was comparable with the N uptake at an application of 44 kg P ha^{-1} alone. Phosphorus uptake was greatest with the application of 44 kg P ha^{-1} in combination with MykoPlus. Application of 22 kg P ha^{-1} plus MykoPlus resulted in P uptake comparable with that at an application of 44 kg P ha^{-1}. P uptake was also very low in the control treatment indicative of the very low P availability in the Jasaan clay.

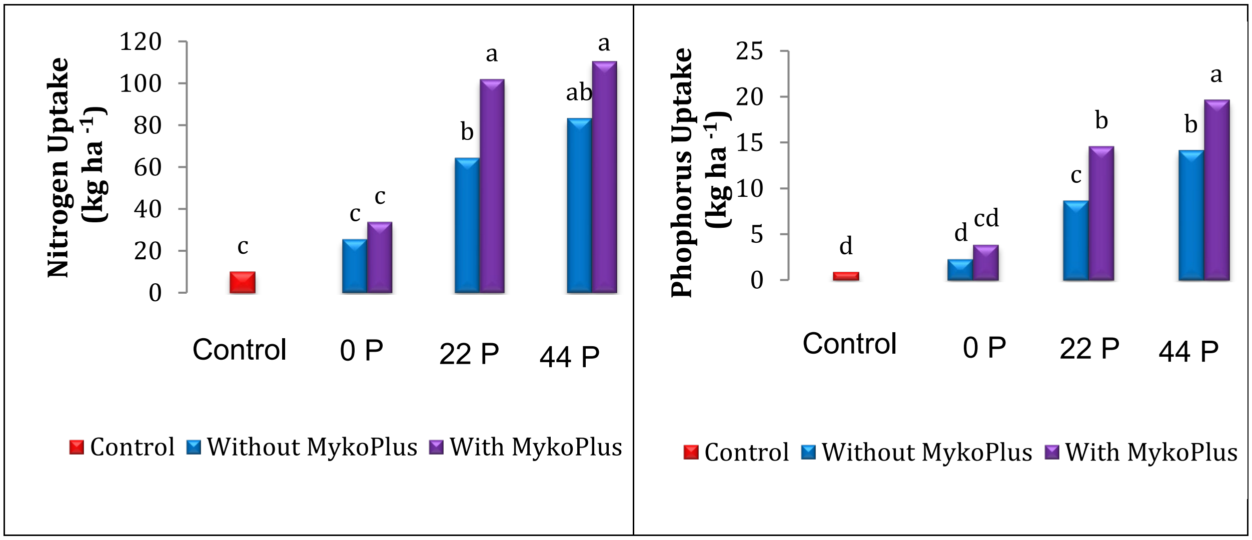


Figure 7.28. N and P uptake (kg ha^{-1}) at harvest as influenced by the application of P and microbial inoculant

Application of P increased available P and was further enhanced when combined with MykoPlus. MykoPlus contains P solubilising microbes that keep the applied P in an available form which reportedly convert unavailable soil P fraction into soluble phosphate for plant uptake (Anand et al., 2015). The levels of exchangeable K, Ca and Mg in the soil were not significantly influenced by the different treatments.

Table 7.35. Chemical properties of the soil as influenced by the application of increasing level of phosphorus and microbial inoculant.

TREATMENTS	pH H_2O (1:5)	pH $CaCl_2$ (1:2)	OM (%)	N (%)	AVAIL. P (mg kg^{-1})	K (cmol$_c$ kg^{-1})	Ca (cmol$_c$ kg^{-1})	Mg (cmol$_c$ kg^{-1})
Control	5.40 ab	4.68 cd	2.96	0.09 b	3.37 e	0.40 b	2.88	0.79
0 P	5.65 ab	5.08 a	3.56	0.11 ab	3.94 de	0.41 b	3.45	0.83
0 P + MykoPlus	5.68 a	5.12 a	3.51	0.11 ab	4.53 bcd	0.43 ab	3.95	0.92
22 P	5.29 b	4.64 cd	3.06	0.11 ab	4.21 cd	0.42 b	2.94	0.84
22 P + MykoPlus	5.71a	4.60 d	3.25	0.13 a	4.79 abc	0.46 ab	2.86	0.93
44 P (RRP)	5.62 ab	4.85 bc	3.22	0.10 ab	5.22 ab	0.49 ab	3.19	0.81
44P + MykoPlus	5.68 a	5.02 ab	3.52	0.11 ab	5.45 a	0.52 a	4.04	0.94

In a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05)

Fertiliser, organic amendment and microbial inoculant effects on cabbage

With the exception of the control treatment the fresh weight of marketable heads ranged from 0.53 kg head $^{-1}$ (with CM application) to 1.06 kg head $^{-1}$ (with CM+44P–RRP) + MykoPlus (Table 7.36). However, this was comparable with the T_{10} Well-grow + 44P (0.98 kg head $^{-1}$), T_3 RRP + MykoPlus (0.92 k g head $^{-1}$), T_6 CM + RRP (0.90 kg head $^{-1}$) and T_{11} Well-grow + RRP + MykoPlus (0.86 kg head $^{-1}$). The total fresh weight increased when the RRP was combined with CM or Well-Grow (Table 7.36). The effect of the different amendments, in combination with MykoPlus, was only observed with CM T_7 (CM + RRP + MykoPlus). However, with Well-Grow application, there was a decrease in total above ground biomass between T_{10} (WG + RRP), (1.80 kg plant $^{-1}$) and T_{11} (WG + RRP + MykoPlus) (1.58 kg plant $^{-1}$).

Table 7.36. Effects of P rate (0, 22 and 44 kg ha^{-1}) and MykoPlus on cabbage plant head fresh weight (Hd_Fr_Wt), total plant fresh weight (kg plant^{-1}) (TotFrWt), wrapper leaf yield (WrLfYld), marketable head yield (MktHdYld), relative yield improvement to Control (RYI) and harvest index in an experiment conducted at Claveria, Misamis Oriental Philippines.

	Hd_Fr_Wt (kg plant^{-1}) **	TotFrWt (kg plant^{-1}) **	WrLfYld (t ha^{-1}) **	MktHdYld (t ha^{-1}) **	RYI	HARVEST INDEX **
Control T_1	0.10 c	0.27 d	8.2 d	6.0 d		0.39 b
44 P (RRP) T_2	0.63 b	1.18 c	26.8 bc	35.5 c	4.9	0.54 a
44 P + MykoPlus T_3	0.92 a	1.60 b	35.5 ab	51.7 ab	7.6	0.58 a
Chicken Manure (CM) T_4	0.53 b	1.06 c	26.5 bc	29.8 c	3.9	0.50 ab
CM + MykoPlus T_5	0.59 b	1.18 c	30.4 abc	33.1 c	4.5	0.50 ab
CM + 44P T_6	0.90 a	1.67 b	32.5 abc	50.7 ab	7.4	0.54 a
CM + 44P + MykoPlus T_7	1.06 a	1.96 a	37.8 a	59.7 a	8.9	0.55 a
Well-Grow (WG) T_8	0.58 b	1.07 c	24.0 c	32.7 c	4.4	0.54 a
WG + MykoPlus T_9	0.59 b	1.14 c	26.2 bc	33.3 c	4.5	0.52 ab
WG + RRP T_{10}	0.98 a	1.80 ab	38.3 a	55.1 ab	8.1	0.55 a
WG + RRP + MykoPlus T_{11}	0.86 a	1.58 b	30.9 abc	48.4 b	7.0	0.54 a

In a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05).

The yield of wrapper leaves was higher when the RRP was combined with CM and Well-Grow (Table 7.36). Increased yield (37.8 t ha^{-1}) was also observed when MykoPlus was applied in combination with CM and RRP compared with no MykoPlus (32.5 t ha^{-1}). Well-Grow and RRIF attained higher yield (38.3 t ha^{-1}) compared with the corresponding treatments with MykoPlus application (30.9 t ha^{-1}). The application of RRP increased the marketable yield from 6.0 to 35.7 t ha^{-1}, corresponding to a 4.89 relative yield improvement (Table 7.36). Combining the RRP with MykoPlus resulted in an additional increase of 16.2 t ha^{-1} (45.7%). The application of organic amendments such as CM increased yield by 23.8 t ha^{-1} (a 3.94 relative yield increase over the control). Combining CM with MykoPlus further increased yield by 10.9 % from 29.8 t ha^{-1} to 33.1 t ha^{-1}, an increase of 3.3 t ha^{-1}. A diverse group of bacteria and fungi is recognised to be involved in microbial phosphate solubilisation mechanisms through which insoluble forms of phosphates can be converted into soluble forms (Walpola and Yoon, 2012).

Nutrient concentration and uptake

The highest at harvest N concentrations in plant tissue (1.97-2.11%) were observed in all treatments receiving 44 kg P ha^{-1} (Table 7.37) highlighting the important role of optimizing P application to improve N use efficiency. With the application of 44 kg P ha^{-1} there was no difference in plant N concentration across the organic amendment and MykoPlus treatments. Application of the organic amendments alone or in combination with MykoPlus resulted in lower total N concentrations. The P concentration of plant tissue was also higher when 44 kg P ha^{-1} was applied alone or in combination with CM or Well-grow with MykoPlus.

Table 7.37. Nitrogen, phosphorus, and potassium concentration (%) in cabbage leaves at 30 DAT and harvest

TREATMENTS	N (%) 30 DAT	HARVEST	P (%) 30 DAT	HARVEST
Control	1.38 c	1.54 d	0.11 e	0.13 f
44 P (RRP)	1.86 ab	1.97 abc	0.28 abc	0.34 cd
44 P + MykoPlus	1.90 ab	2.07 ab	0.33 ab	0.37 c
Chicken Manure (CM)	1.66 abc	1.79 bcd	0.29 abc	0.32 cd
CM + MykoPlus	1.76 abc	1.83 bcd	0.32 ab	0.33 cd
CM + 44P	1.91 ab	2.07 ab	0.34 ab	0.46 ab
CM + 44P + MykoPlus	2.00 a	2.17 a	0.36 a	0.50 a
Well-Grow (WG)	1.75 abc	1.88 abc	0.24 bc	0.38 c
WG + MykoPlus	1.81 abc	2.00 ab	0.29 abc	0.39 bc
WG + RRP	1.96 a	2.07 ab	0.38 a	0.50 a
WG + RRP + MykoPlus	2.01 a	2.11 ab	0.37 a	0.51 a

In a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05).

Soil properties after harvest

Available P increased from 3.37 (mg kg^{-1}) in the control to 4.65 mg kg^{-1}with the application of CM alone ($p<0.05$) (Table 7.38). The combination of CM and Mykoplus further increased the P concentration (6.05 mg kg^{-1}). The highest soil available P was recorded in the CM treatments combined with the RRP (8.96 mg kg^{-1}) and MykoPlus (9.31 mg kg^{-1}). Consistent with amending soils, treatments receiving Well Grow or CM had higher soil organic matter.

Table 7.38. Chemical properties of the soil as influenced by the application of inorganic fertiliser, organic amendments and microbial inoculant.

TREATMENTS	pH H_2O (1:5)	pH $CaCl_2$ (1:2)	OM (%)	N (%)	P (mg kg^{-1})
T_1 – Control	5.40 cde	4.68 cd	2.96 c	0.09 b	3.37 f
T_2 – 150-100-160 (RRIF)	5.62 abc	4.85 bc	3.22 bc	0.10 ab	5.22 de
T_3 – RRIF + MykoPlus	5.68 ab	5.02 ab	3.52 abc	0.11 ab	5.45 de
T_4 – Chicken Manure (CM)	5.78 a	5.13 a	4.19 a	0.12 ab	4.65 e
T_5 – CM + MykoPlus	5.70 a	4.84 bc	3.87 ab	0.11 ab	6.05 cd
T_6 – CM + RRIF	5.34 de	4.58 d	4.10 ab	0.12 ab	8.96 ab
T_7 – CM + RRIF + MykoPlus	5.44 bcde	4.62 cd	4.06 ab	0.13 a	9.31 a
T_8 – Well-Grow (WG)	5.59 abcd	4.75 cd	4.37 a	0.12 ab	4.78 e
T_9 – WG + MykoPlus	5.33 e	4.64 cd	4.11 ab	0.12 ab	6.63 c
T_{10} – WG + RRIF	5.42 cde	4.73 cd	4.09 ab	0.13 a	8.13 b
T_{11} – WG + RRIF + MykoPlus	5.54 abcde	4.77 cd	3.96 ab	0.11 ab	8.77 ab
CV (%)	**1.88**	**1.98**	**9.33**	**11.53**	**6.07**

Table 7.39 shows the analysis of costs and return for cabbage production under different nutrient management practices. Total costs included the expenses incurred as farm inputs and labour. The lowest return on investment (ROI) (0.75) was obtained when no fertiliser or organic amendment was applied in the field. Increasing the P application rate from 0 to 22 to 44 kg P ha^{-1} increased the ROI to 2.18, 4.26, and 4.89, respectively. Application of MykoPlus likewise increased ROI at all P levels. When no P was applied, application of MykoPlus increased ROI by only 0.26. At 22 kg P ha^{-1}, the ROI increased by 1.83 with the application of MykoPlus while an increase in ROI of 1.73 was realised at 44 kg P ha^{-1}. Combining the RRP with MykoPlus resulted in a high ROI (6.62). Application of CM + RRIF + MykoPlus resulted in the highest ROI (7.03). For cabbage production, the most profitable practice is to combine CM + RRIF + MykoPlus. For every peso spent by the farmer, he earns Php 7.03. The usual practice in Claveria, Misamis Oriental is to combine CM + RRIF which in our analysis can provide an ROI of 6.24.

Vegetable production is critical to the economic base of Claveria, Misamis Oriental but vegetable crop production is limited by soil constraints in the acidic upland soils. To meet demand, farmers apply excessive quantities of phosphate fertiliser and lime. Though mineral fertilisers greatly improve yield, their high cost is critical to farmer profits. Therefore, there is a need to optimise the use of P fertiliser and evaluate other management practices such as the use of organic amendments and microbial inoculants to increase yield in these acidic upland soils.

Table 7.39. Cost and return analysis of cabbage and sweet pepper production as influenced by application of inorganic fertiliser, organic amendments and microbial inoculant in Jasaan clay.

TREATMENTS	Total Returns ('000 Php)	Total Cost ('000 Php)	Net Income ('000 Php)	ROI
Control	211	120	90	0.75
0P	537	169	368	2.18
0P + MykoPlus	593	172	420	2.44
22P	1,034	197	837	4.26
22P + MykoPlus	1,576	222	1,354	6.09
44P (RRP)	1,241	211	1,031	4.89
44P + MykoPlus	1,809	238	1,571	6.62
Chicken Manure	1,042	182	860	4.72
Chicken Manure + MykoPlus	1,157	188	969	5.15
Chicken Manure + 44P	1,774	245	1,529	6.24
Chicken Manure + 44P + MykoPlus	2,089	260	1,829	7.03
Well-Grow	1,144	195	949	4.87
Well-Grow + MykoPlus	1,164	196	968	4.92
Well-Grow + 44P	1,927	260	1,667	6.41
Well-Grow + 44P +MykoPlus	1,693	250	1,443	5.77

Micronutrient and bio-fertiliser effects on cabbage yield

The application of Nutrio increased cabbage marketable yield by about 12% compared with the unamended Control and MykoPlus (Table 7.40). The application of RRIF increased marketable yield substantially over the Control, however, the additional application of B (RRIF + B) increased marketable yield by a further 12% over that in the RRIF. Furthermore, a combination of a half rate of the RRIF gave a marketable yield (38.2 t ha^{-1}) similar to that in the RRIF treatment (38.5 t ha^{-1}) indicating that N, P and K were not the major limitations to cabbage growth (Table 7.41). A combination of a half rate of RRIF with micronutrients (+B,Zn,Mo,Cu) gave a marketable yield (45.7 t ha^{-1}) similar to that in the full RRIF with B or with BZnCuMo. This data highlights that B deficiency is a problem in the upland acidic soils and this is consistent with the cabbage leaf survey finding. The response to chicken manure presumably corrects micronutrient deficiencies though soil and plant tissue B is essentially not analysed in The Philippines. Notwithstanding, the marketable yield in the RRIF+CM (55.9 t ha^{-1}) was greater than that in RRIF+BZnMoCu (46.5 t ha^{-1}) hence it is likely, based on the previous results, that the higher P load of chicken manure provides a further P response. The response to chicken manure requires further elucidation, but presumably, to a large part, it relates to micronutrient and P supply.

Table 7.40. Effects of Nutrio and MykoPlus on cabbage marketable head yield in an experiment conducted at Claveria, Misamis Oriental Philippines.

Marketable yield (tons ha^{-1})		
Nutrio **	MykoPlus **	No Biofertiliser **
45.3 a	40.8 b	39.7 b

Table 7.41. Effects of fertiliser and micronutrient treatments on cabbage marketable head yield in an experiment conducted at Claveria, Misamis Oriental Philippines.

Treatments	Marketable Yield (t ha^{-1})
Control	6.6 e
RRIF	38.5 d
RRIF+B	48.5 abc
RRIF+Zn	40.6 cd
RRIF+Mo	42.4 cd
RRIF+Cu	40.9 cd
RRIF+BZn	47.2 bc
RRIF+BZnMoCu	46.6 bcd
½ N+PK	38.2 d
½ N+PK+BZnMoCu	45.7 bcd
RRIF+CM	55.9 a
RRIF+CM+BZnMoCu	52.0 ab

[1] In a column, means with the same letter(s) are not significantly different according to Tukey HSD (0.05)

7.5 Studies on root system performance

Solution culture experiments (DAF and UPLB) were conducted to assess acidity and aluminium limitations on vegetable growth.

Pythium, pH and Al effects on root growth

In the 2 experiments conducted to evaluate effects of pH on bean root growth a solution pH of 4.2 gave a substantial reduction in root growth compared with pH values of 4.5, 4.8, and 5.1 (Table 7.42). In Experiment 2 there was no significant difference in root growth between pH values of 4.5, 4.8 and 5.1. However, in Experiment 1 a pH of 5.1 gave significantly greater root growth than at pH values of 4.5 and 4.8. Effects of pH on root fresh weight were not significant ($p<0.05$) probably due to the variability in root system saturation with nutrient solution, measured immediately at harvest. This experiment identified that a solution pH of 4.5 is acceptable for running bean bioassay experiments that assess effects of soil acidity.

Table 7.42. Effect of nutrient solution pH on mean root length and mean fresh weight in bean plants grown in solution culture over a 5 day period.

Solution pH	Root Length (mm)			
	Expt 1		Expt 2	
4.2	64.7	c	145.4	b
4.5	124.6	b	173.6	a
4.8	141.2	b	184.1	a
5.1	165.4	a	185.4	a
F Test Prob.	<.001		<.001	
LSD	23.65		13.33	

The assessment of effects of pH and Pythium on root growth response shows that the incidence and severity of Pythium was worse at low pH (Table 7.43). In both experiments, the net difference in root system growth between the Pythium inoculated plants and non-inoculated plants, at the same pH, showed the negative effect of Pythium was directly related to lower pH. At pH 5.1 there was minimal difference in root growth between inoculated plants and the non-inoculated plants (a difference of 27-33 mm) whilst at pH 4.2 the difference was considerable where the roots of inoculated plants were 86-100 mm shorter than their counterpart non-inoculated control plants.

Table 7.43. Effect of Pythium and nutrient solution pH on root lesion number, mean root length and root length difference between Pythium treated plants and untreated plants at the same pH in 2 experiments (PyExp1 and PyExp2) on bean plants grown in solution culture over a 10 day period.

Solution pH	Root lesion (no./plant)		Root Length (mm)				Root Length difference (mm)			
	PyExp1	PyExp2	PyExp1		PyExp2		PyExp1		PyExp2	
4.2	4.0	4.75	40	c	44	c	100	a	86	a
4.5	2.8	4.5	82	b	89	b	51	b	48	b
4.8	1.0	4.0	107	a	113	a	17	c	19	c
5.1	2.3	4.75	98	ab	101	ab	27	bc	33	bc
F Test Prob.	0.055	0.389	<.001		<.001		<.001		<.001	
LSD	NS	NS	24.2		22.3		24.2		22.3	

At pH 4.5, with progressive increases in Al concentration from 0-30 μm both mean root length and root fresh weight declined (Table 7.44). The overall reduction in root length varied across experiments but substantial reductions occurred at 30 μm Al compared with the 0 μm treatment whilst an Al concentration of 10-20 μm gave an intermediate reduction in root growth. Hence Al concentrations of 10-30 μm provide a range of plant growth responses suitable for evaluating the interaction between nutrient solution Al concentration and Pythium infection.

Table 7.44. Effect of solution Al concentration (μm) on mean root length and mean root fresh weight in bean plants grown in solution culture at pH 4.5 over a 5 day period.

Al conc. (μm)	Root Length (mm)						Root Fresh Weight (g)				
	Expt 3		Expt 4		Expt 5		Expt 3		Expt 4	Expt 5	
0	130	a	96	a	166	a	0.25	a	0.17	0.39	ab
5	76	b	80	b	165	a	0.17	b	0.21	0.42	a
10	67	bc	47	c	139	b	0.14	c	0.13	0.34	ab
15	75	b	44	c	137	b	0.17	b	0.14	0.33	ab
20	76	b	43	c	130	b	0.16	bc	0.12	0.30	bc
30	52	c	40	c	90	c	0.15	bc	0.12	0.20	c
F Test Prob.	<.001		<.001		<.001		<.001		0.065	0.006	
LSD	17.33		15.77		19.29		0.0309			0.103	

The research, using green bean as a test species, showed that reducing solution pH from 5.1 to 4.2 progressively increased root sensitivity to infection by the pathogen pythium. In the absence of pythium, increasing Al concentration from 0 to 30 μM gave progressive reductions in root growth. However, in the presence of pythium the 0 μM had the poorest root growth and root growth increased with the addition of 10 and 20 μM Al but declined with a further increase to 30 μM Al. The result suggests that the low Al concentrations either affect the viability of pythium or its pathogenicity or Pythium reduces soluble Al. In support of this other findings identify that the pathogen *Pythium* has a capacity to alkalise growth media (PDA and V8 growth media) raising pH from an initial 4.0 to about 6 over a period of about 7 days. Further research suggests Al suppresses *Pythium* development. A review of the literature highlights the inadequacy of previous studies that have considered the relationship between Al toxicity and pathogens, where poor control of solution pH and matrix compromise the quality of the research. The present research has provided a fundamental understanding of the role of soil chemical factors in predisposing plants to pathogen infection as well as potential effects for inducing pathogen suppression.

Capsicum root studies

The first experiment evaluated the effects of Al on capsicum root growth. The effect of Al was not significant though the longest root length was recorded in the 0 μM Al treatment and the shortest was recorded in the 30 µM Al treatment (Table 7.45). Of interest the roots did not display symptoms of shortened, thickened and blunt roots normally associated with Al toxicity. Rather, roots were mealy and fine, and more consistent with a low pH (acidity *per se*) effect. Further solution culture research on the effects of acidity have shown that commercial capsicum cultivars are more sensitive to solution pH than to Al. Progressive reductions in capsicum root growth occurred with a pH change from 5.1 to 4.2 (pH 5.1, 4.8, 4.5 and 4.2). In contrast, the inhibitory effect of Al on root growth occurred at a pH of 4.5. A subsequent experiment evaluated the effect of pH on root growth and identified that capsicum is highly sensitive to increasingly acidic pH (Table 7.46). Root growth progressively declined with a reduction in pH from 5.1 down to 4.2.

Table 7.45. Effect of solution Al concentration (µm) on mean root length in capsicum plants grown in solution culture at pH 4.5 over a 10 day period.

Al Concentration (µM)	Root length (cm)
0	13.1
10	11.5
20	9.3
30	8.7

Effect was not significant at p≤0.05

Table 7.46. Effect of solution pH on mean root length and mean root fresh weight and shoot weight in capsicum plants grown in solution culture over a 12 day period.

Solution pH	Root length (mm)		Root wt (g)		Shoot Wt (g)	
4.2	40	c	0.053	d	0.190	b
4.5	87	b	0.093	c	0.241	a
4.8	109	a	0.118	b	0.256	a
5.1	123	a	0.148	a	0.252	a
LSD (5%)	21.2		0.024		0.035	
F Prob.	<0.001		<0.001		0.002	

Further ongoing research on capsicum root system improvement has identified a suite of about six elite rootstocks that confer greater productivity of when grafted with commercial capsicum scions. To understand mechanisms for growth improvement a solution culture experiment was conducted to compare root growth between the six wild accessions and two commercial cultivars (cvs. Warlock and Plato) over a range of pH values from 4.2 to 6.0. This experiment has shown that the commercial cultivar root systems are negatively affected by declining pH to a far greater extent than the wild accessions (Fig. 7.29). With a drop in pH from 6.0 to 5.4 the root length in the commercial cultivars (cvs. Plato and Warlock) declined by 10% but there was no difference in root growth for accessions 40-5 and 45-2-1 at these pH values. Further reductions in pH from 5.4 to 4.5 had a more substantial effect on the commercial cultivars (a 40-50% root growth reduction) compared with the accessions 40-5 and 45-2-1 (a 20% reduction in root growth). At the lowest pH all genotypes had reduced root growth but the wild accessions nonetheless had substantially greater root growth than either of the commercial cultivars Warlock and Plato.

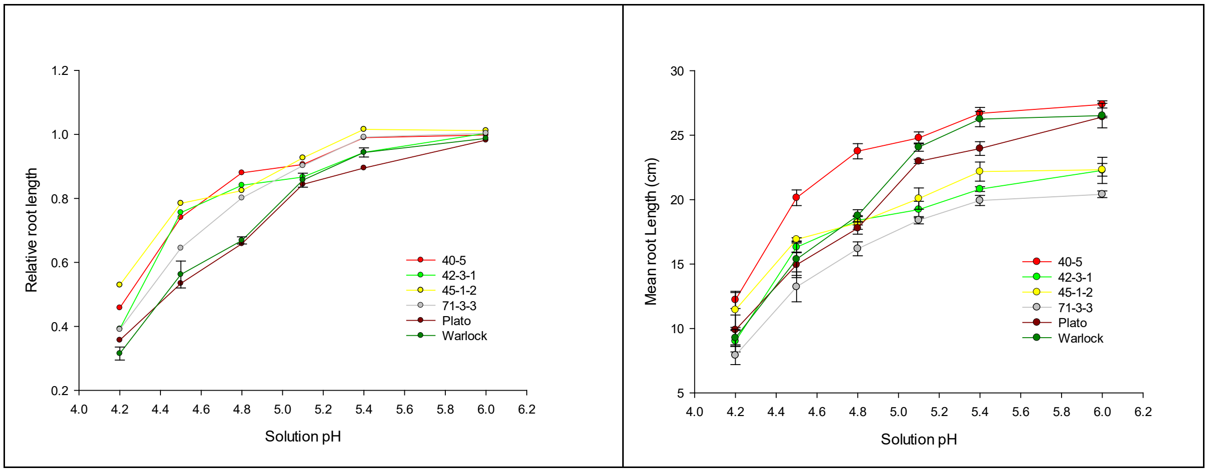


Figure 7.29. Effect of solution pH on relative root length and mean root length in four accessions of *Capsicum chinense* and two commercial bell pepper cultivars in solution culture over a 14 day growth period.

This research highlights that the root systems of commercial capsicum cultivars have high sensitivity to pH that is likely to negatively impact on root growth and crop productivity. In general many crop species are only affected by pH *per se* when solution pH is less than 4.5. This research shows that capsicum is more sensitive to pH than other species. The pH values where capsicum roots are damaged is greater than the solution pH where Al impacts on root growth (pH 4.5). In vegetable production liming is commonly practiced to achieve a soil pH of greater than 5.0, however, this data indicates that root damage due to pH could still reduce productivity and predispose plants to pathogen infection. Further research on sweet peppers is required to identify the impact of moderate acidity on root damage, crop productivity and predisposition to root pathogen infection. The research challenges concepts around liming rates for optimal crop production and highlights the opportunities for root system selection for tolerance to abiotic stresses such as low soil pH. This would have considerable benefits to poor farmers in tropical climates for whom availability and cost of lime is a major productivity impediment. This is particularly the case if, with current cultivars, there is a need to raise pH from 5.0 to 6.0 on acidic variable charge soils.

7.6 Vegetable product quality and crop nutrition

Sweetcorn Zn biofortification

Experimentation has investigated the potential of biofortifying sweetcorn with Zn through either agronomic or genetic biofortification. Kernel Zn concentration in a 'High zeaxanthin 103146' line was approximately three-fold higher than the standard variety 'Hybrix 5'. In a vertisol soil, fertilisation with Zn up to a rate of 6 kg Zn ha^{-1} did not increase kernel Zn concentration in either variety. A subsequent fertiliser trial using a sand-perlite-peat mix demonstrated that soil Zn fertilisation up to a rate of 12.8 mg kg^{-1} did increase stem and foliage tissue Zn concentration by more than two-fold, however in the kernels there was only a 20% increase in Zn concentration. A further study evaluated the kernel Zn concentration in a broad range of germplasm. The study identified that kernel Zn concentration is directly related to kernel size and number and hence effectiveness of pollination. Subsequent studies determined that rate of individual kernel Zn accumulation is higher in poorly-pollinated cobs than in well-pollinated cobs, whereas rate of dry matter accumulation is similar. This resulted in poorly-pollinated cobs expressing higher kernel Zn concentration than in well-pollinated cobs. Using the Australian Synchrotron in Melbourne, it was determined that at the immature kernel stage of sweetcorn harvest and consumption, most of the Zn is accumulated in the embryo of the kernel. Approximately 80% of the immature kernel Zn is in the human digestible form of Zn-phosphate. Further research has demonstrated Zn is present as non-bioavailable Zn-phytate.

Table 7.47. Mineral concentrations for dried bulb samples across a range of AVRDC garlic germplasm.

Selection	Type	otal %	NH4+-N	Nitrate N	P%	K%	S%	Ca%	Mg%	Na%	Cl%	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zinc mg/kg	Boron mg/kg	Mo mg/kg
		%	mg/kg	mg/kg	%	%	%	%	%	%	%		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
AVRDC - 6	ST	4.20	1600	680	0.41	2	0.53	0.77	0.46	0.02	0.44	150	68	2.4	30	38	0.64
AVRDC - 7	ST	4.60	1500	500	0.37	1.9	0.46	0.88	0.47	0.02	0.52	170	69	2.5	33	41	0.78
AVRDC - 8	ST	4.60	2200	390	0.42	1.9	0.58	0.79	0.41	0.02	0.41	140	78	3.1	36	45	0.59
AVRDC - 9	ST	4.40	1900	510	0.42	1.8	0.59	0.8	0.43	0.02	0.37	150	81	3.3	35	41	0.56
AVRDC - 10	ST	4.60	2400	370	0.42	2.2	0.98	0.54	0.36	0.01	0.63	160	66	4.3	34	28	0.83
AVRDC - 11	ST	4.60	1200	720	0.37	2.3	0.49	0.85	0.47	0.03	0.68	150	67	3	32	29	0.78
AVRDC - 12	ST	4.50	1400	420	0.4	1.8	0.53	0.9	0.48	0.02	0.44	170	73	3.1	34	42	0.7
AVRDC - 16	T	4.60	1500	630	0.48	2.2	0.94	0.95	0.55	0.01	0.6	210	100	6.1	38	21	1
AVRDC - 17	T	4.20	1300	590	0.4	1.9	1	1.1	0.55	<0.01	0.57	210	83	5.2	36	25	1.3
AVRDC - 18	T	4.10	950	320	0.4	2	0.96	0.85	0.46	0.01	0.66	230	190	5.7	45	18	1
AVRDC - 19	T	4.00	1400	420	0.33	1.9	0.99	1.1	0.56	<0.01	0.75	200	78	5.6	34	23	1.1
AVRDC - 20	T	3.90	1200	530	0.36	1.9	0.98	1	0.54	<0.01	0.62	230	110	5.1	37	21	0.95
AVRDC - 21	T	4.10	1100	580	0.38	2.1	1	0.99	0.52	<0.01	0.6	170	97	5.2	35	22	0.9
AVRDC - 22	T	3.90	1000	350	0.35	1.8	0.94	1.4	0.66	<0.01	0.82	310	99	5.1	41	27	1.3
AVRDC - 23	T	3.90	1000	310	0.47	2.1	0.76	1.2	0.62	<0.01	0.61	190	120	5.2	27	24	0.9

denotes relatively low

denotes sufficient

denotes sufficient to high

8 Impacts

The learnings derived from conducting project experimentation and from engaging with vegetable farmers through meetings and trainings organised within the project have been applied to the teaching and research activities of the Philippine educational partners from VSU, USTP and UPLB. This has improved agricultural science training outcomes for Philippine undergraduate and postgraduate students. The project has also enhanced the visibility of the project partners to other vegetable soil and nutrition researchers and vegetable farmers in the Philippines and particularly the priority focus areas for the project. The project has enhanced the collaboration among the partner institutions, which will deliver better research outcomes into the future. A key example of this is the relationship between UPLB and USTP. At the USTP Claveria research facility, high quality applied collaborative field experiments have been completed. Under this, postgraduate students from UPLB have been based at USTP, over the duration of experiments, as part of their studies. UPLB provides high level analytical and science input.

8.1 Scientific impacts

The project has developed a bioassay technique to evaluate the effects of pH and Al toxicity on vegetable crops for which only limited worldwide research has been conducted. The project has provided the resources to establish the technique, and, training and ongoing advice, has been provided to the Philippine project partner UPLB to implement the technique, which is now functioning well and this line of experimentation is continuing past the project's completion.

In Australia, this bioassay technique has been further refined to assess the interaction between soil acidity factors (Al toxicity and low soil pH) and soil health indicators (using Pythium, a low grade pathogen, as a plant health indicator species). This research has shown that the incidence of Pythium increased with decreasing pH to 4.2. A further experiment has evaluated the Pythium-Al toxicity interaction and this data. The findings also identify that Pythium has the capacity to alkalise growth media (PDA and V8 growth-media) raising pH from an initial 4.0 to about 6 over a period of about 7 days. A review of the literature highlights that previous studies on this interaction, though technically sound from a pathology perspective, have failed to understand the dynamics of acidic soil chemistry particularly in relation to Al.

Mostly the studies have used solutions with very high ionic strength not representative of soil solution, fail to maintain pH at a level appropriate to keep Al^{3+} in solution, and have used Al concentrations far in excess of the concentrations that result in plant root damage. A study on the relationship between agar growth medias and complexation of Al show that at a media Al concentration of 20 µM less than 5 µM of the Al is in the free monomeric form the remained is as complexed Al on charged sites in the agar. A review of the scientific literature on the relationship between Al toxicity and pathogen survival revealed methodology faults where complexation of Al by agar media was not accounted for resulting in the likely overestimation of Al concentration effects on pathogens. Preliminary results indicate that high Al concentrations can induce pathogen suppression but the effect of Al forms is not understood at this point. This study represents a major step forward in understanding the contribution of soil chemical factors in the development of pathogen suppressive soils and link soil chemical properties to the biology and expression of soil pathogens. Soil pathogens are a key constraint in vegetable production systems that operate under tight crop rotations.

Further research has evaluated the direct effects of pH on root system development of capsicum. In solution culture, a reduction in solution pH from 6.0 to 5.1 reduced root growth in two commercial capsicum cultivars by 15 % and was reduced by about 40% with a reduction in pH from 6.0 to 4.8. Typically, recommendations for liming acidic soils target a soil pH of about 5 to overcome Al toxicity but this research highlights liming rates in capsicum may need to be higher to avoid root damage.

The project has delivered a comprehensive set of data (soil and plant analyses) and experimental results to assess nutrient limitations in Philippine vegetable production systems which will be published in a journal along with an assessment of vegetable farmer soil and nutrient management practices. The identification and application of nutrient omission technique is a step forward in Philippine scientific capacity. Research on food quality traits and their association with crop nutrition is also a novel finding that will be published and establishes an objective basis for linking soil quality effects with food quality traits.

In Australia, research on bunching onion where foliage colour is a key marketing issue identifies that the rate and form of applied N affects yield and visual quality. The use of UAV-drone imaging allowed the identification of differences in foliage quality not easily discerned by the human eye. Furthermore, it has highlighted cultivar differences in yield and foliage spectral properties in response to N rate and form.

Research on Zn biofortification using sweetcorn has shown that agronomic biofortification based on foliar Zn application combined with genetic improvement can substantially increase kernel Zn concentration. Research conducted at the Australian synchrotron has shown that early accumulation of Zn in the kernel is mostly in the edible embryo. However, the form of Zn in the embryo is predominantly as non-bioavailable Zn-phytate which is in contrast to the simpler forms of Zn in the kernel endosperm.

8.2 Capacity impacts

Australian vegetable and research facility tour

A large contingent of the Philippines team (10 members) attended a special training exercise in Queensland, Australia from 17 to 30 April 2016. Participants included 10 collaborators from the 4 partner institutions in the Philippines (V.B. Asio, G.C. Añonuevo, S.B. Lina, C.M.O. Quiñones, R. Salas and A.B. Tulin from VSU; G. Nilo and K. Bautista from BSWM; P. Sanchez from UPLB; and A.B. Gonzaga from USTP. The host and organisers were S Harper, B Powell and N Menzies.

The training exposed Philippine scientists to modern well equipped research laboratories at two research precincts maintained by the Queensland Government and with a particular focus on soil and plant analysis and food quality analysis. Similarly, the group toured the soil and nutrition research laboratories and facilities at The University of Queensland. The team also received training in solution culture techniques, root system evaluation using rhizotrons and laboratory based bioassays to assess Al toxicity in soil and solution culture at the Queensland DAF Gatton Research Facility. Stephen Harper also demonstrated how field vegetable experiments are conducted using drip irrigation and fertigation to accurately apply nutrient treatments. Discussions with the team highlighted this technique could easily be adopted in the

Philippines to deliver improved experimental outcomes by lowering experimental variability as well as commercial outcomes through implementation with Philippine vegetable farmers. The team conducted a series of field trips to assess the variability in aged soils in Australia and landscape management processes with a particular focus on modern intensive vegetable production systems. The aged Australian landscapes are in stark contrast to those observed in the Philippines and the team observed soil types that they had not seen before. These learnings will now be included in the educational and training programs of the partner institutions.

Furthermore, the UPLB delegate Dr Pearl Basilio Sanchez was provided a solution culture kit including plumbing, hydroponic light, air pump and miscellaneous fittings. This has enabled the Philippine team to make assessments of the impact of Al toxicity and acidity on the various vegetable species and cultivars grown in the Philippines.

Field activities

The project has strengthened the capacity of the partners in conducting research on soil fertility, nutrient budgeting, nutrient omission trials, the bioassay for aluminium toxicity and other aspects of soil fertility research. In particular, this skilling has been on vegetable cropping systems which are complex and intensively managed compared with many other agricultural systems. The field surveys and field visits increased the researchers' awareness of the soil-related problems besetting small and large-scale vegetable farmers in the Visayas and Mindanao, and the complexity of field problems associated with vegetable production. The field visits to Bohol, Claveria, Davao and Leyte have set an informative background understanding for the Philippine partners in that they learned and applied the basic skills to differentiate between, nutrient and physiological disorders, and disease symptoms in vegetable crops and to appreciate the different soil management strategies and motivations employed by subsistence and commercial vegetable farmers. The development of this knowledge complements the extensive experience the teams hold in other cropping systems (field crops and plantation crops) allowing teams to better address complex agricultural system production issues and research.

Postgraduate training

Under the project, there has been ongoing training of undergraduate and postgraduate students in both The Philippines and Australia through VSU, UPLB, USTP and UQ.

VSU have trained 4 MSc and 3 BS students who have conducted their theses as part of the project. The MSc Soil Science students were Gerry May Anonuevo (2018), Marvin Cascante (June 2018), Rene Jane Alesna (June 2018), and Mica Binongo (June 2018). The BS Soil Science students were Ress Belmores (June 2018), Evelyn Abrematea (June2018) and Niezel Jane Estrellanes (June 2017). Their theses were focused on the impact of intensive vegetable production on the soil fertility/quality in Cabintan as well as on the effect of liming on the performance of vegetables. Ms. Anonuevo's thesis was on P availability in acidic soils from Leyte and Samar most of which are used for vegetable production. Furthermore, staff from VSU employed under the project have completed or initiated studies overseas including two PhD (Germany) and one Master Agr. Sc. (Taiwan).

- Cecille Quiñones received a PhD scholarship to Germany to follow research initiated in this project.
- Mel Adelle Ocba has received a scholarship for a M. Science in Agriculture (major in soil science) Taiwan.

Four students from USTP Claveria have completed their dissertations on nutrient use efficiency of cabbage and fertiliser (Dr. Chona Q. Allego), and pest dynamics in vegetables under the open field and protected structure (Dr. Elvira T. Salatan), Cabbage plant population density and N fertilizer rate (Dhayan Allego, MSc) and farmers pesticidal usage survey (Lanelyn Bustamante MSc) .

Three students from UPLB and one from USTP have conducted their M. Sc. field trials in conjunction with USTP at Claveria, evaluating productivity of sweet pepper and cabbage with the application of organic and inorganic fertilisers (Jessabel B. Magtoltol, MSc, Vergitt B. Magtoltol, MSc and Jeany Dacup, MSc) and nutrient omission pot trials on maize, sweet pepper and cabbage (Joana Rose M. Vergara MSc).

In Australia, postgraduate training directly linked to the project includes:-

- Binh Nguyen (PhD student - UQ) is evaluating the relationship between garlic mineral nutrition and the concentration of the nutraceutical allicin across tropically adapted germplasm.
- Rusmi Wiyati (Master of Philosophy UQ) is evaluating the interaction between pH, Al and pathogen infection (the non-obligate pathogen Pythium).
- Anthony Kipkurui (Master of Agr Studies UQ) completed his master of studies experiment on the genetic potential to improve root systems in conferring tolerance to drought.
- Cheah Zhong (PhD student - UQ) has investigated the potential of biofortifying sweetcorn with Zn through agronomic and genetic biofortification.
- Minguo Li commenced PhD studies in April 2019 evaluating the interaction between soil factors (eg pH, EC, NO_3^-, Al^{3+}) and root growth across Capsicum (pepper) germplasm.

Other training

Sarah Lyn A. Pepito, Research Assistant (USTP), participated in two training workshops, Writing Scientific Journals for Peer-Reviewed Journals (VSU) and Writing Scientific Articles for Publication in ISI Journals at Central Mindanao University, Musuan, Bukidnon.

Victor Asio provided expert services during the scientific paper writing workshop organised by the ACIAR Vegetable ICM project team at VSU (VSU) on 6-10 June 2016.

A 3 day statistics training program was held for staff at VSU in June 2017. This included 12 staff members and covered research data analysis. Topics covered included experimental design, data distribution, data variability, experimental design, factorial analysis, variability (standard deviation and standard error) and levels of significance.

Training on Statistical Analysis of Research Data was held for all ACIAR Vegetable Soil and Crop nutrition Project Staff (June 2017).

Victor Asio delivered a seminar on scientific writing to graduate and undergraduate students in the College of Agriculture and Food Science on 28 April 2018. The seminar was co-sponsored by the Department of Agronomy, Department of Soil Science, and the ACIAR Vegetable Soil Crop Nutrition Project.

R. Salas conducted a training workshop on hydroponics vegetable production for agriculture technicians held at the Department of Horticulture, VSU, Baybay, Leyte on June 15-16, 27-30, 2016. Resource person was.

V.B. Asio, G.C. Añonuevo, S.B. Lina, and C.M.O. Quiñones participated in the Annual Conference of the Visayas Division of the National Research Council of the Philippines held on 23 May 2016 in Cebu City.

V.B. Asio, G.C. Añonuevo, S.B. Lina, and C.M.O. Quiñones participated in the Workshop on Proposal Writing organised by the Visayas Division of the National Research Council of the Philippines on 24 May 2016 in Cebu City.

A soil and vegetable training excursion was conducted by the VSU project team to Samar Island and was conducted for junior research staff and graduate students of VSU (November 3-4, 2015).

Maribel Jalalon was successful in receiving a John Dillon Fellowship and completed this in November 2018.

Key project results were presented at Scientific Conferences (Philippine Society for the Study of Nature and The International Conference on Nature Study and Innovation for the Environment) April 2017.

Three seminars were delivered by the Australian partners to the academic staff and graduate and undergraduate agriculture students of VSU on November 5, 2016 at VSU. These included

- "Field diagnostics of disorders in vegetable crops'' Stephen Harper (November 5, 2016 at VSU).
- "The challenge of predicting metal transfer through the soil-plant-animal continuum" Neal Menzies. (November 5, 2016 at VSU).
- "Garlic crop nutrition and improvement" Stephen Harper (USTP - 23 February 2018 and UPLB 6 March 2018).

Apolinario B. Gonzaga Jr. and Nelda R. Gonzaga presented during the 4th AFSA International Conference on Food Safety and Food Security (AFSA2018) last August 10-12, 2018, at Angkor Paradise Hotel, Siem Reap, Cambodia. This included:-

- Performance and postharvest quality of tomato (Solanum lycopersicon Mill) as influence by different level of nitrogen fertilizer.

- Growth, yield, and postharvest quality of cabbage (Brassica oleracea Linn) in response to different level of nitrogen fertilizer.

8.3 Community impacts

Engagement with farming community members has been made through the soil and plant survey sampling exercise. The project has identified key suppliers of fertilisers and amendments, which has allowed these businesses to be included in the extension of outcomes.

8.3.1 Economic impacts

The research has also identified the optimal range of the high input nutrients (N, P and K) for vegetable production in the Philippines across a range of soil types. In particular, the research has identified optimal rates of N application in peppers, cabbage, tomato and eggplant for conventional production and optimal rates for chicken manure (the main source of organic nutrient) application for organic production systems. Subsequent field research evaluated these identified rates to complete an economic assessment that compares the productivity and profitability of organic and conventional vegetable production. The identification of optimal fertiliser application rates (particularly N) allows crop yield potential to be maximised whilst reducing excessive fertiliser application; a major issue in the key vegetable production regions of Claveria, Bukidnon and Leyte.

Omission trials have been conducted over a range of soil types including calcareous and acidic soils to identify underlying soil and nutrition constraints to vegetable crop productivity. The identification of these constraints is important in addressing reductions in crop yield. Furthermore, the optimal liming rates for vegetable production on acidic soils have been identified to allow farmers to apply appropriate rates to achieve maximum crop yields. The identification and remediation of currently undiagnosed nutrient limitations (particularly micronutrients) will improve the productivity and quality of vegetable crops and deliver improved nutrient use efficiency (particularly N). The sum of these improvements allows farmers to reduce their input costs, particularly for N, P, and lime. Fertiliser inputs represent about 30% of a vegetable farmers costs in the Philippines. The strong positive responses to biofertilizers in combination with mineral fertilizer application also warrant further evaluation: MykoPlus consistently improved yields and nutrient uptake.

The research has also identified optimal application rates for chicken manure in organic production systems. The required rates are such that sourcing sufficient volumes of broiler chicken manure to meet a large scale conversion of Philippine vegetable production to organic production is not possible. The research has also demonstrated that yields of organic production systems are substantially lower than conventional systems. The difference in this yield relates to poor crop nutrition under organic production. An economic assessment of the impact of the improved practices is now being undertaken.

8.3.2 Social impacts

The project provides a set of data and guidelines that can improve the yield and quality of vegetables by optimising nutrient inputs to match crop demand. The improvements in the quality and yield of vegetables has direct social impacts by improving consumer health and confidence and can improve the affordability of purchasing vegetables.

Surveys of reference vegetable leaf samples suggest that there is excessive application of fungicides (including copper) used in controlling key vegetable pathogens. Further confirmation of this is required and improved and targeted management programs are required to reduce usage of these.

8.3.3 Environmental impacts

Survey data of vegetable farmer practices and field surveys for soil and crop plant tissue has established that excessive application of fertiliser (particularly N) is a serious concern in intensive vegetable production in the Philippines. The project has completed a range of trials that evaluate the effects of different fertiliser strategies with the aim of optimising inputs to match productivity. A series of experiments have been conducted in Cabintan and Claveria to establish N response profiles for tomato, capsicum, eggplant and cabbage in wet and dry seasons. The development of these crop N response profiles allows more balanced applications of fertiliser to match seasonal yield potential and forms the basis for reducing excessive fertiliser application and losses to the environment.

A series of nutrient omission trials over a range of soils have identified micronutrient limitations to crop productivity. Currently, these potential micronutrient problems remain undiagnosed and micronutrient application is essentially not practiced. The identification and correction of micronutrient limitations in Philippine vegetable production can improve crop growth and yield and allow improved macronutrient nutrient use efficiency, particularly N This combined with the development of crop N response profiles (for wet and dry season) will allow for more balanced applications of fertilisers and form the basis for reducing excessive fertiliser application and losses to the environment.

While excessive application of mineral fertilisers is a key environmental issue, reliance on organic manures alone to fertilise crops does not maximise biomass production and this has the potential to result in greater soil exposure and increased system predisposition to soil loss. Furthermore, organic manures have concentrations of major nutrients (N, P and K) that do not match crop demand profiles. Hence excessive application of chicken manure to meet crop N requirements results in P application of about 20 times crop uptake and K application at about 1.5 times crop uptake.

8.3.4 Other impacts

The project has completed long-term (3 year) trials that have evaluated differences in the effectiveness of nutrient management practices in organic and conventional vegetable production systems. The research has demonstrated that vegetable crop yields are considerably lower from systems relying solely on organic nutrient inputs compared with systems where both mineral and organic nutrient sources are used. Furthermore, systems that rely only on organic nutrient inputs have delayed harvest and produce less than half the fruit number of systems that use mineral fertiliser (also in combination with organic fertilisers). A well-managed conventional production system, that uses both mineral and organic nutrient sources, produced about 5 times the yield of systems where the sole source of nutrient input is organic. The project has identified the rates of manures and composts required to maximise vegetable crop yields and presents data that should be carefully considered in any push to promote organic production at a governmental level as it would impact on food security and price. The promotion of organic production should be considered in the context of the market capacity to pay a premium price for organic products.

The project has delivered a comprehensive set of data for soil and plant samples from Philippine vegetable production systems which will be published in a journal along with an assessment of vegetable farmer soil and nutrient management practices. This information can be used by The Philippine government to assist in prioritising its soil and nutrient management strategies and research investment for vegetable production systems.

8.4 Communication and dissemination activities

Project surveys and field excursions

The project team has conducted intensive surveys of key Southern Philippines vegetable production areas (Leyte, Claveria, Bohol, Bukidnon, and Samar). Survey protocols were developed and discussed with team members in September 2014 and in February 2015 training was held in the application of these protocols on vegetable farms. This included soil and plant analysis and nutrient budgeting.

This survey activity has not only allowed the development of quality objective data but also allowed direct engagement with farmers to identify priority issues impacting on production. The team has provided individual feedback to these farmers. A major training exercise on soil fertility assessment for improved crop nutrient management in vegetable production was facilitated by Landcare Foundation Philippines Inc. in collaboration with VSU and was attended by twenty-five collaborating farmers (identified from the survey) representing the key districts of Samar, Leyte and Bohol. The results of the field survey, particularly the soil and plant analysis enhanced the farmers' knowledge and appreciation of the importance of soil and plant analysis in identifying what nutrients are required and how much nutrient to apply to their vegetable crops. It has helped farmers identify the key nutritional factors that are likely to be impacting on the productivity of vegetable cropping, resulting in a change in farmer perceptions on issues associated with soil and nutrient management.

VSU Conducted a soil excursion to Samar Island to observe vegetable farms, soils and landscapes for Australian partners and junior research staff and graduate students of VSU on November 3-4, 2015 (VSU) organised by V.B. Asio, S.B. Lina, and C.M.O. Quiñones.

Project staff workshops and training

The project had its inception meeting which was attended by all project collaborators as well as ACIAR and PCAARRD representatives on May 15-16, 2014 at the Quest Hotel, Cebu City. After the meeting, a field visit was conducted to the proposed research site in Cabintan, Ormoc, Leyte was held.

Follow-up project team meeting was held at VSU, Baybay City, Leyte on Sept 17-19, 2014 followed by site visits to Cabintan, Ormoc City and Claveria, Misamis Oriental.

A project meeting was held on Feb 16, 2015 at the Malberry Hotel in Cagayan de Oro City to discuss project progress and was followed by site visits to Claveria on Feb 17 and Davao Feb 18-21, 2015.

Landcare Foundation Inc. and VSU conducted a training workshop on soil fertility assessment for improved crop nutrient management participated in by selected vegetable farmers from Bohol, Leyte, and Samar (interviewed during the field surveys) on 22-23 June 2016.

Meetings have been held with individual farmers and farmer groups in several of the key production areas. The aim has been to outline the focus of the project and discuss and identify the key soil and nutrient issues from the farmer's perspective and present survey data to participating farmers.

Farmer training and workshops

The VSU project team has developed training materials and the program includes knowledge and practical skills across a comprehensive suite of issues including:

- Problems in vegetable production
- Field survey findings from Leyte, Bohol and Samar.
- Sharing of experiences and problems.
- Approaches for addressing nutritional problems in vegetables
- Visual diagnosis of nutrient disorders, soil and plant testing
- Soil testing plant analysis and interpretation.
- Soil health and integrated nutrient management and good nutrient management practices
- Vegetable production and climate change - promoting productivity under climate change and importance for health and environment.
- A guide to growing vegetable production including grafting for soil pathogen management general agronomy of vegetable cropping.

Considerable farmer training has been conducted including:-

- 75 participants attended training at Lantapan Bukidnon (June 27-28 2017).
- 70 participants attended training in Davao (Nov 8-9 2017).
- 60 participants attended training in Impasug-ong Bukidnon (May 22-23 2018).
- 80 participants attended training at USTP Claveria (May 24-25 2018).
- Farmer field day conducted at USTP Claveria Nov 2017.
- 209 people attended the USTP farmer field day event in Claveria Dec 13-14 2017.

Furthermore project staff from VSU conducted farmer training (26 farmers) in conjunction with the College of Agriculture and the Department of Environmental Science at Southern Leyte October 2016. This training focussed on modern practices for soil and nutrient management. The training allowed farmers to express their concerns over issues relating to soil and nutrient management. A further farmer training was conducted by VSU staff with the Southern Leyte State University in June 2017. At the initiation of each of the trainings a pre-test was conducted to assess the initial knowledge of farmers and a final test evaluated farmer knowledge post-training. The average pre-training test score was 20% and at the end of the training the average score was 80%.

The Philippine Landcare project staff attended the soil and nutrition training at VSU and subsequently delivered training in the conflict affected areas in Mindanao under the ACIAR-ASEM project.

A Farmer’s Field Day (September 2016) was held in Claveria to highlight cabbage responses to N application.

More than 100 farmers from different parts of Leyte have visited the vegetable experiments during the Farmers Field Day on April 26, 2018. Rosario Salas, Suzette Lina and Victor Asio served as resource personnel.

In June-July 2018 Victor Asio, Suzette Lina, Deejay Maranguit and Rosario Salas visited 12 villages in Basey and Marabut Samar to assist their vegetable/food crop production as part of the partnership between the College of Agriculture and the NGO ‘Food for the Hungry’. Many of the farmers’ problems related to vegetable production and so the ACIAR project team provided further ongoing technical assistance.

Lectures

Asio V.B. 2016. Why publish in peer-reviewed publications? Lecture delivered during the Training-Workshop on Scientific Paper Writing for Peer-reviewed Publications organised by the ACIAR-ICM Project on 6-10 June 2016 at VSU, Baybay City, Leyte.

Asio V.B. 2016. Understanding soil, soil fertility and plant nutrition. Lecture delivered during the Soil Fertility Assessment Training for Improved Crop Nutrient Management, 22-23 June 2016, VSU, Baybay City, Leyte.

Lina, S.B. 2016. Reporting of soil/plant analysis result and giving of recommendations. Lecture delivered during the Soil Fertility Assessment Training for Improved Crop Nutrient Management, 22-23 June 2016, VSU, Baybay City, Leyte.

Quiñones, C.M.O. 2016. Methods of assessing soil fertility status. Lecture delivered during the Soil Fertility Assessment Training for Improved Crop Nutrient Management, 22-23 June 2016, VSU, Baybay City, Leyte.

Three guest lectures were delivered by the Australian partners to the academic staff and graduate and undergraduate agriculture students of VSU on November 5, 2016 at VSU. These included

- “Field diagnostics of disorders in vegetable crops’’ Dr Stephen Harper (November 5, 2016 at VSU).
- “The challenge of predicting metal transfer through the soil-plant-animal continuum” Prof. Neal Menzies. (November 5, 2016 at VSU).
- “Garlic crop nutrition improvement research” Dr Stephen Harper (USTP - 23 February 2018 and UPLB 6 March 2018).

Dr. Apolinario B. Gonzaga (USTP) was a guest speaker during the farmers training at Lantapan, Bukidnon entitled “Training on Soil and Nutrient Management Strategies for Improving Vegetable Production at Bukidnon” last June 27-29, 2017. Sarah Lyn A. Pepito and Renan P. Octavio (part of ACIAR-BSWM/ USTP Team) also participated.

Series of Farmers Training and Workshop on Soil and Nutrient Management Strategies in partnership with BSWM Lantapan Bukidnon n=60 (a), Davao City n=74 (b), Claveria Misamis Oriental n=80 (c); hands on activity using Soil Test Kit (STK) (d & e)

Farmers Field Day (a) and Techno Forum (b) at USTP-Experiment Station. Farmers Field Evaluation of Cabbage Under Protected Structure (c) and Open Field on Different Levels of N Fertilization (d)

A highlight of the project capacity building was a visit to Australia by 10 members of the Philippine project team representing four of the collaborating groups from 17 to 30 April 2016. The training provided a broad training opportunity that included specialised laboratory based studies and demonstrations, field experimental sites, commercial farming operations and landscape production issues. The latter having a particular focus on the 'old' Australian soils and landscape that contrasts with the young Philippine landscape. The solution culture bioassay technique for assessing Al toxicity effects on vegetables was implemented from this trip by UPLB and is now being used effectively used to evaluate impacts of soil acidity constraints (pH and Al) and

Media items and videos

Qld DAF has produced a draft YouTube video clip on how to conduct a nutrient budget, which will assist researchers and extension officers to implement a nutrient budget evaluation with vegetable farmers. The aim is to identify fertiliser use efficiency https://youtu.be/6lKPU6GQIXA.

An early morning (5:00AM to 6:00AM) airing at USTP FM Radio Station presented the 2017 Radio University on Soil Fertility Management with Dr Apolinario B Gonzaga Jr as the Resource Person together with USTP Extension Associate Mr Rosewin Sevandal on November 21, 2017.

Scientific publications, conferences and presentations

Salas, F.M., Salas R.A., V.B. Asio, S. Harper. 2016. Growth, yield, and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) applied with different levels of chicken manure. Poster paper presented during the 2nd National Organic Congress on Feb. 16-18, 2016 held at VSU, Baybay City, Leyte.

Salas, F.M., Salas R.A. Asio, V.B. and Harper S. 2016. Yield and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) applied with different levels of chicken manure. Oral paper presented during the International Conference for Nature Studies and Innovations for the Environment May 24-27, 2016, Dumaguete City.

Cheah ZX, Kopittke PM, Harper SM, O'Hare TJ, Wang P Paterson DJ, De Jonge MD, Bell MJ. (2018). In situ analyses of inorganic nutrient distribution in sweetcorn and maize kernels using synchrotron-based X-ray fluorescence microscopy. *Annals of Botany*, mcy189, https://doi.org/10.1093/aob/mcy189.

Zhong CX, Kopittke PM, Harper SM, Meyer G, O'Hare TJ, Bell MJ (2019) Speciation and accumulation of Zn in sweetcorn kernels for genetic and agronomic biofortification programs. *Planta* https://doi.org/10.1007/s00425-019-03162-x

Cheah ZX, Kopittke PM, Scheckel KG, Noerpel MR and Bell MJ. (in preparation) Comparison of Zn accumulation and speciation in sweetcorn and maize embryo and endosperm at different stages of kernel maturity using synchrotron-based X-ray absorption spectroscopy.

Cheah ZX, O'Hare TJ, Harper SM, Kochanek J and Bell MJ, (2018). Zinc biofortification of sweetcorn for human health, Acta Horticulturae. International Horticultural Congress (IHC2018), 12-16 August, Istanbul.

Cheah ZX, Harper SM, O'Hare TJ and Bell MJ (2018). Elevated Zn concentration in zeaxanthin-biofortified sweetcorn kernels compared to commercial hybrid, Acta Horticulturae. International Horticultural Congress (IHC2018), 12-16 August, Istanbul.

VSU has submitted a poster paper on the growth, yield, and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) under different levels of chicken manure (2nd National Organic Congress on Feb. 16-18, 2016).

VSU presented an oral paper on the yield, and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) under different levels of chicken manure (International Conference for Nature Studies and Innovations for the Environment May 24-27, 2016).

Apolinario B. Gonzaga Jr., Nelda R Gonzaga, Sarah Lyn Pepito, Renan Octavio and Stephen Harper (2018). Performance and postharvest quality of tomato (Solanum lycopersicon Mill) as influence by different level of nitrogen fertizer. 4th AFSA International Conference on Food Safety and Food Security (AFSA2018) last August 10-12, 2018, at Angkor Paradise Hotel, Siem Reap, Cambodia.

Apolinario B. Gonzaga Jr., Nelda R Gonzaga, Sarah Lyn Pepito, Renan Octavio and Stephen Harper (2018). Growth, yield, and postharvest quality of cabbage (Brassica oleracea Linn) in response to different level of nitrogen fertilizer. 4th AFSA International Conference on Food Safety and Food Security (AFSA2018) last August 10-12, 2018, at Angkor Paradise Hotel, Siem Reap, Cambodia.

9 Conclusions and recommendations

9.1 Conclusions

The project has completed a comprehensive survey that has identified key soil and nutrient constraints to vegetable cropping systems. The variability in soil types, from strongly acidic (pH 4.5) to highly alkaline (pH 8.2) soils, results in a multitude of problems and site to site variability in specific issues that require remediation. The upland acidic soils are used intensively for vegetable production due to specific soil qualities and the upland environment that is favourable for growing a large range of vegetables. Excessive application of N, P, and K are key issues though site specific variability was identified. For example, in the same region, some farms will have deficiencies of P and K whilst others may have high P and K status. To address this, the project has developed optimal fertiliser rates for wet and dry season production in the priority crops including, tomato, sweet pepper, cabbage, and eggplant. Assessments of food quality traits in relation to crop nutrient management strategies shows that key food quality traits (ascorbic acid and free radical scavenging) are greatest under the optimised nutrient management regimen.

Despite the generally excessive fertiliser application, farmers when surveyed would identify poor soil fertility as a key vegetable productivity constraint and this was the basis for excessive application of high fertiliser rates. In the Cabintan area of Leyte and Claveria in Mindanao, soil acidity remains a significant productivity constraint along with undiagnosed micronutrient deficiencies that reduce crop productivity. Hence failure to understand key limitations is likely to result in inappropriate crop fertiliser management strategies (i.e excessive application of the wrong elements). This was supported in one study where application of half of the recommended rate of NPK fertiliser combined with micronutrient application gave cabbage yield greater than the full recommended NPK rate alone. Further nutrient omission trials identified multiple micronutrient deficiencies that impact on vegetable growth. From this, the likely crop limitations are now well understood and sites can be selected where a range of practice changes/treatments can be evaluated.

Use of some biofertilizer products, in combination with mineral fertilizers, has produced yields in field trials that substantially exceed the yield produced by mineral fertilizers alone. However, the mechanism by which the yield increase is achieved has not been elucidated. As there are a range of potential mechanisms by which the biofertilizer could act (including increased P supply through the action of solubilizing organisms, supply of micronutrients, direct hormonal impact of the organism on the plant), more detailed evaluation of the mode of action of these products will be needed to optimize their use.

High concentrations of Cu, Zn and Mn were identified in vegetable soil and plant tissue samples. For Cu and Zn these related to high application rates of crop protection products and chicken manure and this issue requires further attention.

The research has shown that, from a crop nutrition perspective alone, the productivity of organic vegetable production systems is substantially lower than systems that use mineral and organic nutrient forms. The application of chicken manure at typical rates used by Philippine vegetable farmers and rates identified as optimal for organic production give strongly unbalanced nutrient application in relation to crop demand. This results in strongly excessive P and K application and the micronutrients Cu and Zn. A standard application of chicken manure (~10 t ha^{-1}) applies 20 times the whole crop demand for P and 8 times that for Cu highlighting the strong potential for negative environmental impacts. These issues, combined with the limited availability of chicken manure, should be considered in programs that promote farmer adoption of organic production. With the implementation of policies and programs that promote wide-scale adoption of organic production practices effective management of crop nutrition to deliver high yield represents a major challenge.

9.2 Recommendations

Further research on a range of key issues in vegetable production systems is required, particularly with reference to soil and nutrient management. Broadly, this includes issues of excessive nutrient application, undiagnosed nutrient deficiency limitations, unbalanced nutrient input programs, metal ion accumulation and soil pathogen management.

The improved management of excessive inputs of mineral fertilisers is a key issue and the implementation of more effective nutrient management strategies including protected N-fertiliser forms, fertigation and long term monitoring of soil fertility changes under intensive production is desirable.

The need to resolve undiagnosed micronutrient deficiencies is important in improving vegetable system productivity and the efficiency of N, P, and K fertiliser use. Micronutrient limitations, and particularly molybdenum and boron, are problematic as there is limited Philippine capacity to analyse for these and to subsequently develop good diagnostic criteria to assess limitations. Furthermore, availability of these minerals in acidic soils, with high aluminium and potential fixation reactions, is not well understood. Characterisation of the productivity response of vegetables to micronutrients, the development of analytical skills and judicious management of these are a key concern and threat to productivity of Philippine vegetable production.

Evidence has been collected, through soil and reference leaf survey data, that highlights extremely high concentrations of Cu, Zn and Mn in the most important vegetable production areas of the southern Philippines. This finding is consistent with the identified excessive inputs of pesticides (bactericides and fungicides) and high rates of chicken manure. The long-term direct effect of high application rates of these heavy metals, relative to crop demand, and, the subsequent accumulation in soils, warrants research attention from a crop productivity and food safety perspective.

The heavy reliance on chicken manure as a soil amendment not only contributes to this problem but it also results in strongly unbalanced nutrient inputs in relation to crop demand resulting potentially causing deleterious environmental impacts.

A range of serious soil pathogens are very serious constraints to vegetable crop productivity and include Ralstonia (bacterial wilt - in tomato, capsicum and cucurbits), Clubroot (brassicas) and Fusarium (tomato and capsicum). In some areas, strains of Ralstonia are so aggressive they seriously infect eggplant which is normally used as a Ralstonia resistant grafting rootstock. Addressing the soil pathogen constraints requires a multidisciplinary approach using genetic resistance, grafting, soil organic amendments, probiotics and optimised management of soil-acidity through liming. On the latter point, the research has highlighted that capsicum (pepper) sensitivity to pH *per se* is higher than that typically identified in other crops. Understanding the effect of pH on root growth in vegetables and its impact on the expression of soil pathogens is a key research issue. Linked with this, the overall improvement of soil quality and diagnostics for problematic soils (acidic, salt affected and calcareous alkaline soils) should be considered along with the identification of key microbiological and biochemical soil properties.

Soil organic carbon management remains an issue and the incorporation of leguminous trees, tree residues and herbaceous legumes (eg. *Arachis pintoi*, Lablab) amongst other rotations, offers potential to build resilient soil carbon, improve soil quality and reduce soil losses from vegetable production in the upland high rainfall zones. This, along with more efficient major nutrient fertiliser use efficiency and correction of micro-nutrient limitations, could allow reduced application of chicken manure and establish more sustainable vegetable production systems with lower environmental impact.

A review of existing extension materials for soil and fertiliser recommendations is required and further updating of these recommendations to include the key project findings is important. Subsequently an extension program to support farmers in implementing these would be desirable. The capacity to analyse a greater suite of micronutrients in soil and plant tissues is desirable for researchers in the Philippines to improve research and crop productivity outcomes.

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10.2 List of publications produced by project

Salas, F.M., Salas R.A., V.B. Asio, S. Harper. 2016. Growth, yield, and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) applied with different levels of chicken manure. Poster paper presented during the 2nd National Organic Congress on Feb. 16-18, 2016 held at VSU, Baybay City, Leyte.

Cheah ZX, Kopittke PM, Harper SM, O'Hare TJ, Wang P Paterson DJ, De Jonge MD, Bell MJ. (2018). In situ analyses of inorganic nutrient distribution in sweetcorn and maize kernels using synchrotron-based X-ray fluorescence microscopy. *Annals of Botany*, mcy189, https://doi.org/10.1093/aob/mcy189.

Zhong CX, Kopittke PM, Harper SM, Meyer G, O'Hare TJ, Bell MJ (2019) Speciation and accumulation of Zn in sweetcorn kernels for genetic and agronomic biofortification programs. *Planta* https://doi.org/10.1007/s00425-019-03162-x

Cheah ZX, O'Hare TJ, Harper SM, and Bell MJ. (in preparation) Kernel number and kernel mass as tools for predicting nutrient concentrations in sweetcorn kernels.

Cheah ZX, Kopittke PM, Scheckel KG, Noerpel MR and Bell MJ. (in preparation) Comparison of Zn accumulation and speciation in sweetcorn and maize embryo and endosperm at different stages of kernel maturity using synchrotron-based X-ray absorption spectroscopy.

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Cheah ZX, Harper SM, O'Hare TJ and Bell MJ (2018). Elevated Zn concentration in zeaxanthin-biofortified sweetcorn kernels compared to commercial hybrid, Acta Horticulturae. International Horticultural Congress (IHC2018), 12-16 August, Istanbul.

Rose Salas submitted a poster paper on the growth, yield, and post-harvest qualities of two genotypes of eggplant (Solanum melongena L.) under different levels of chicken manure (2nd National Organic Congress on Feb. 16-18, 2016).

11 Appendixes

Appendix 11.1 ACIAR Project SMCN/2014/029 Plant sampling protocol for diagnosing nutritional limitations

Australian Government
Australian Centre for International Agricultural Research

Survey protocol soil and plant sampling

project	**Soil and Nutrient Management Strategies for Sustainable Vegetable Production in Southern Philippines**
project number	SLaM/2012/029
prepared by	Dr. Stephen Harper and Prof. Victor B. Asio

ACIAR Project SMCN/2014/029 Plant sampling protocol for diagnosing nutritional limitations

Field Survey Protocol-ACIAR Vegetable Soil Project SMCN-2012-029

Instruction for researchers on how to conduct the survey

A. **Objective of the exercise**

The overall aim of the project is to develop soil and nutrient management practices for smallholder farmers in the Southern Philippines so as to increase cost-effective production of vegetables.

B. **Site Information**

The following site information will be gathered from each vegetable farm in selected sites in Bohol, Leyte, Samar, Davao and Northern Mindanao.

Grower to fill out:

1. Gender: ________________
2. Name of Owner/Farmer:____
3. Age: _____
4. What is the total area (hectare) of all plots you currently cultivate?______________
5. Is the majority of your plots or parcels upland or lowland parcels?_____________________
   Upland (flat but not for rice) ( )Lowland (flooded rice, flat) ( ) Hilly lands (sloping)
6. Historical site preparation.
   Brought in soil ( ) Removed top soil ( ) Original/Normal soil ( )
7. Marital Status : Single ( ) Married ( ) Widowed ( ) Separated/Divorced( )

   Common Law/Live-in ( )

8. Years of schooling & Highest Educational Attainment:___________________________
9. Number of children: ___________

Researcher to fill out:

10. Vegetable Farm No. _________________
11. Address:____
12. Coordinates and Elevation (using GPS):
    a. Longitude _______ b. Latitude _______ c. Elevation _____________
13. Soil (to be obtained from soil map):
    a. Soil Series: _________ b. Soil Type:______ c. FAO/USDA Classification:______
14. Type of Climate:____________ Dry Months:____________________(eg April to June)
    Rainy Months:________________

C. Information on Farming Activity

15. What is the land tenure?______________________
    1-Cultivating own land ( ) 2-Shareholder / Tenant () 3- rented ()

    a. If you are a shareholder, what is the share arrangement (%)?
    b. Do you actively take part in the decision making on the farm together with the land owner? Please discuss with farmer _eg crop choice, fertiliser use, pesticide etc

16. Source of irrigation or water (e.g. river, spring)

17. Major vegetables grown (rank according to importance)
    a) Sweet pepper _____
    b) Eggplant _________
    c) Cabbage _________
    d) Tomato __________
    e) Others___________

18. Yield per cropping (t/ha) : ____________
19. Cropping pattern: ____
20. Cropping schedule: ____
21. Crop and soil management practice

Crop & Soil Management	Sweet Pepper	Eggplant	Cabbage	Tomato	Other vegetable (specify)	Other vegetable (specify)
Area (ha)						
Planting density (plants/ha)						
Yield/crop (tonne/ha) (wet/dry)						
Varieties used (variety name)	Brand					
Land preparation (number of times plowed; mechanical/manual						
Nursery activities						
Planting time???						
Mineral Fertilisers						
1. Kind						
1. Amount (kg/ha)						
2. Kind						
2. Amount (kg/ha)						

3. Kind						
3. Amount (kg/ha)						
4. Kind						
4. Amount (kg/ha)						
5. Kind						
5. Amount (kg/ha)						
Soil amendments (e.g. lime, compost, manure, compost tea) and rate of application						
1.Rate of application						
Frequency (yearly, 2yrs, 3 yrs)						
2.Rate of application						
Frequency (yearly, 2yrs, 3 yrs)						
2.Rate of application						
Frequency (yearly, 2yrs, 3 yrs)						
3.Rate of application						

Frequency (yearly, 2yrs, 3 yrs)						
4.Rate of application						
Frequency (yearly, 2yrs, 3 yrs)						
Water management (e.g. sprinklers, drip)						
Weeding						
Mulch (e.g. plastic; plant residues						
Spraying						
Other pest control measures						
Harvesting						
Marketing						
Trellis						
Prune						

Length of growing season						
Others						

22. Perception of cost of inputs

Cost of Inputs/Labor Cost per hectare	Sweet Pepper	Eggplant	Cabbage	Tomato	Other vegetable (Specify)	Other vegetable (Specify)
Source of seeds/Cost (P)						
Land Preparation						
Weeding						
Fertilisers (organic/inorganic)						
Chemicals (spray)						
Harvesting						

D. Soil sampling, processing and analysis

Soil samples will be collected from each vegetable farm according to the following procedure:

1. Divide the farm into homogeneous parts based on soil type, drainage, crops, or topography.
2. In each homogeneous area, collect at random 10 subsamples from 0-20 and 20-40 soil depths using a core sampler or soil auger. Place all the 0-20cm samples together in a plastic pail, mix well, get about 0.5 kg composite sample and place in a labeled plastic bag. Do the same for all the 20-40cm samples.
3. Avoid collecting samples near roads, fence rows, tree lines or buildings.
4. Take a photo of the site and close up of soil.
5. To air-dry the samples, carefully remove roots and rock fragments in each soil sample and then spread it on a clean manila paper placed on a laboratory table. This will take about 3 days.
6. Following drying, crush the soil samples by using a wooden hammer and then let it pass through a No. 10mesh (2-mm screen). Keep this in properly labeled plastic bags for use in most soil analyses. Additionally, crush further a tablespoon full of the 2-mm sample and allow it to pass a No. 60mesh (0.25mm screen) for organic carbon and total nitrogen analyses.

All soil samples will be analysed for the following physical and chemical properties:

Soil physical properties: particle size distribution, bulk density, and total porosity.

a. *Particle Size Distribution*- the percent sand, silt and clay will be determined by the Hydrometer method.
b. *Bulk Density* (g/cm^3)- this will be determined using the core method. Ten core samples will be collected from the surface soil of each farm for bulk density determination.
c. *Total Porosity* (%)- this will be calculated from the bulk density and particle density values using the formula:

$$P = \left(1 - \frac{Db}{Dp}\right) \times 100$$

Where:

P = total porosity (%)

Db = bulk density (g/cm^3)

Dp = particle density (g/cm^3). Use a value of 2.65 g/cm^3

Soil chemical properties: pH, organic carbon, cation exchange capacity, base saturation, total N, available P, exchangeable bases (K, Ca, Mg, Na), exchangeable Al, and micronutrients (Fe, Mn, Cu, Zn)

a. *Soil pH*- This will be analysed potentiometrically using soil to water ratio of 1:5. Additional optional pH determinations: Using water and 0.01 M $CaCl_2$ at a soil: solution ratio of 1:2.5.
b. *Soil Organic C* (%)- This will be analysed following the Modified Walkley-Black method (Nelson and Sommers, 1982). Note: selected soil samples from some experiments (e.g. conventional vs organic) will be analysed in Australia using CNS analyzer to serve as reference.
c. *Total N* (%)-This will be analysed using the micro-Kjeldahl method (Bremner and Mulvaney, 1982).
d. *Available P* (mg/kg)- Extraction of P will be done according to the Bray #2 method (acidic soil) and Olsen Method (alkaline soil) and quantified using UV-VIS spectrophotometry after color development by ascorbic acid molybdenum blue method (Jones, 2001).
e. *Cation Exchange Capacity* ($cmol_c$/kg soil)- CEC will be determined by the summation of cations method. (Exchangeable bases will be extracted by 1N ammonium acetate and quantified using atomic absorption spectrophotometer. Exchangeable Al will be determined by the KCl method below).
f. *Exchangeable Al* ($cmol_c$/kg soil)- This will be analysed using 1 N KCl as extractant followed by titration of the resulting extract with 0.1 N NaOH (Thomas, 1982).
g. *Base Saturation* (%)- This will be calculated by dividing the sum of K, Mg, Ca, and Naby the CEC (both in $cmol_c$/kg soil)and multiplying the result by 100.
h. *Micronutrients* (Cu, Zn,Mn, Fe in mg/kg)- these will be extracted by DTPA (Jones, 2001) and quantified using an atomic absorption spectrophotometer.

E. Plant tissue sampling, processing and analysis

1. Tissue sampling and processing

Tissue samples of sweet pepper, tomato, cabbage and eggplant will be collected from each vegetable farm included in the survey as follows (Jones, 2001; McGinnis, 2012):

Crop	Stage of Growth	Plant Part to Sample	No. of Plants to Sample
Sweet pepper	Early fruiting	Young mature leaf	20
Tomato	Prior to or during early fruit set	Third or fourth leaf from growing tip	20-25
Eggplant*	Early fruit set	Most recently mature leaf plus petiole	20-25
Cabbage	Prior to heading	First mature leaves from center of the whorl	10-20

*www.blackpaddock.com.au

Plants to avoid during sampling are those that:

- Have suffered long-term climatic or nutritional stress;
- Have been damaged mechanically or by insects;
- Are infested with disease;
- Are border row plants or shaded leaves within the plant canopy;
- Contain dead plant tissue.

Plant sample handling and processing:

- All plant samples will be placed in plastic bags and will be kept cool in an ice box for transport to the laboratory.
- They will be washed with distilled water, blotted dry using clean tissue paper, and will be dried in a forced draft oven at 80ºC for about three days.
- They will be mechanically ground using a Wiley mill fitted with a 20-mesh screen.
- The ground tissue samples will be placed in paper bags and stored in a desiccating cabinet ready for analysis.
- In the field take a representative field and close up photo for plants at each site so that this may be used for visual diagnosis or extension if required.

2. Nutrient content analysis

The following procedures will be followed:

1. *Total N* (%)- this will be analysed by Kjeldahl method (Bremner and Mulvaney, 1982)
2. *Total P* (mg/kg)- samples will be dry ashed at 500ºC for 6-8 hours followed by quantification of P by UV-VIS spectrometric procedure after color development by ascorbic acid molybdenum blue method (Jones, 2001).
3. *Total amounts of K (%), Ca (%), Mg (%), Na (%), Mn (mg/kg), Zn (mg/kg), Cu (mg/kg), Fe (mg/kg)*- samples will be dry ashed at 500ºC for 6-8 hours followed by quantification of mineral elements by atomic absorption spectrophotometry (AAS) (Jones, 2001).

Important reminder:

Soil and plant tissue sampling should be done as soon as possible on any vegetable crop existing in each farm. Re-sampling can be done later for the correct growth stages.

Australian Government

Australian Centre for International Agricultural Research

Survey protocol for cabbage

project	**Soil and Nutrient Management Strategies for Sustainable Vegetable Production in Southern Philippines**
project number	SLaM/2012/029
prepared by	Dr. Stephen Harper and Prof. Victor B. Asio

Appendix 11.2 ACIAR Project SMCN/2014/029 Plant sampling protocol for diagnosing nutritional limitations

Background

Plant analysis for nutrients is a useful tool for assisting in the diagnosis of nutrient limitations and for optimizing rates of nutrient application. It is particularly useful for diagnosing micronutrient limitations where plant uptake (represented by plant tissue concentrations) is a more sensitive indicator for disorders than is the soil concentration of the nutrient. For example the general plant sufficiency range for Zn is in the order of about 30-50 mg kg^{-1} in plant leaf matter but in the soil the sufficiency range is narrow and in the order of about 1.5-2 mg kg^{-1} in soil.

Furthermore, there is not always good correlation between the nutrient uptake by the plant and soil nutrient concentration. The availability of most nutrients, and particularly micronutrients, is directly related to soil pH and associated issues. Both low pH (4.5-5.0) and high pH (>7.8) can reduce the availability of micronutrients giving lower plant uptake. Plant tissue testing identifies what the plant has taken up rather than what is measured from the soil. Other tools such as omission trials and foliar application (particularly for micronutrients) to gauge plant response are also important techniques that should be used to assess the nutrient limitations.

A divergent range of symptoms of nutrient limitations have been observed in vegetable crops in The Philippines and these have varied across crops, districts and soil types. Diagnosis of nutrient disorders in these crops on the basis of visual symptoms alone is not reliable since classic (textbook) symptoms are not always shown and plant tissue testing is required in attempting to definitively assess the limitation.

Plant tissue testing can be used to identify a general low nutrient status (“Hidden Hunger”) or in some situations specific limitations where thrifty (healthy) and unthrifty (unhealthy) plants may be present within a field.

In this project we are interested in diagnosing nutrient disorders and nutrient limitations to crop growth. The protocol here outlines a survey method and a comparison method (poor and healthy plants) for diagnosing nutrient disorders using cabbage as a case study.

However, the protocol should be applied to other vegetable crops when these crops are nearby or where these vegetables more prominently show a nutrient disorder. There is considerable variability across vegetable species in both the extent and visual expression of nutritional symptoms. As examples, sweet corn or maize a very good indicators for Zn limitations whilst brassicas particularly broccoli strongly express B and Mo deficiency. Furthermore the sampling should be done in conjunction with other nutrient diagnostic techniques.

Aim of the sampling exercise

The aim of this survey sampling is to identify the mineral status of cabbage crops that will assist in the identification and understanding of nutrient limitations in vegetable crops.

Survey method for diagnosing disorders

The observed nutritional limitations in vegetable crops in southern Philippines is often relatively uniformly distributed across the fields. That is, patches of healthy crop and poor crop were generally not well defined within one planting. At the project team meeting February 2017 we proposed to conduct a sampling survey of cabbage crops to evaluate the nutrient status across a range of farmers crops (using plant analysis) and matching this with farmer fertiliser application and visual imaging of crop health to aid with diagnosis.

The survey will be conducted across a range of farmers crops using cabbage as a reference crop. To obtain a good data set the samples will be taken across a range of farms that have varying soil properties and use different crop input strategies. It is suggested that samples are taken from about 20 farms in each of the priority districts of Claveria, Cabintan and Bohol (if possible) as well as Bukidnon. The following steps will be used.

1. Assess the field variability to identify whether parts of the crop exhibit well defined healthy or poor crop growth. If there is a clear demarcation in symptoms between healthy and unhealthy plants use the poor-healthy plant comparison method described below.
2. Collect a representative sample (about 20 reference leaves) from the cabbage crop using a grid pattern to cover the field. The reference leaf for cabbage should be taken at about 56 days after transplanting and will be the youngest mature leaf blade.
3. Take GPS coordinates from the site for reference.
4. Take digital images of the affected plants in the field (including a general field and close up image).
5. Photograph the soil.
6. Collect information from the farmer on the application of mineral fertilisers, wastes, manures and amendments as well as foliar fertilisers.
7. If practical collect yield data from the site at maturity.
8. If you think it is worthwhile, you may wish to collect a series of about 10 soil sample cores (0-10 cm) from the crop, bulk and mix these then retain a small air-dried sample (about 200g) for analysis, if required.

Sampling to compare poor and healthy plants within a single crop

One of the best methods to diagnose nutrient limitations is to sample from healthy (asymptomatic) and poor (symptomatic) plants in a field and directly compare the nutrient status of the samples across a suite of analytes. This method is described below.

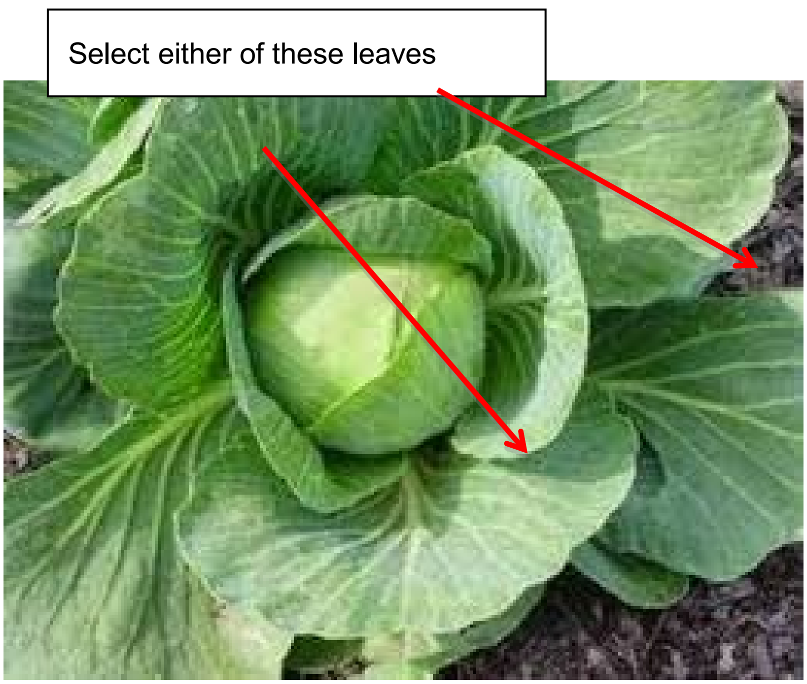
Identify the severity and distribution of the symptoms within the affected crop and identify if there are healthy patches/parts of crop in the field. Look for areas in the crop where the symptoms are different (presence of multiple symptoms) and note any changes in soil colour or texture that would indicate potential explanations for the different symptoms.

1. Collect a sample (about 15-20 leaves) from unhealthy plants that clearly show the symptoms. However, if the symptoms are too severe select plants with slightly milder symptoms as analysis of severely affected plants can exhibit unusual levels of various nutrients. There is no rule in making the decision, it is a value judgement.
2. Take GPS coordinates from the site for reference.
3. Take digital images of the affected plants in the field (including a general field and close up image).
4. Photograph the soil.
5. Collect information from the farmer on the application of mineral fertilisers, wastes, manures and amendments as well as foliar fertilisers.
6. If you think it is worthwhile, you may wish to collect a series of about 10 soil sample cores (0-10 cm) from the crop, bulk and mix these then retain a small air-dried sample (about 200g) for analysis, if required.

Repeat the procedure described above in a part of the paddock that is displaying healthy or at least noticeably better growth. Make sure that the samples collected from the poor and healthy crops are of the same physiological age and of the same cultivar. If the visual symptoms of the disorder are variable within the crop (ie there are multiple symptoms) then you may wish to take several separate samples of the plants showing poor growth.

What part to sample and how many?

In general, the part of the plant that is sampled will be the youngest fully expanded leaf (the most recently matured or full-sized leaf) that includes the whole leaf (leaf blade or lamina, midrib and the petiole). In the reference text *Plant Analysis An Interpretation Manual* the sample reference leaf is listed as the wrapper leaf or young mature leaf; though the citation is a pers. comm. Collect the samples at 50-70 days after transplanting. Collect about 15-20 leaves from each site and place these in a paper bag to prevent the sample from sweating. If the samples are contaminated with dust, soil or chemical, brush the fresh samples with a toothbrush or wash them with deionised water. In the field keep the samples cool, in an icebox with ice until these can be taken to a laboratory and dried in the dehydrator (67^{o}C) or stored short-term in a refrigerator prior to dehydrating.



Avoid sampling damaged, dead or dying plant tissue and plants stressed by environmental conditions, (e.g. drought, flood, extreme, cold heat etc.) or disease. Check with the farmer when he last applied fertiliser and avoid sampling if fertiliser has been applied within the previous 14 days. Farmers generally spray a range of chemicals so check with the farmer on what was last sprayed and when and use protective clothing as required.

The following nutrients should be analysed (if possible); NO_3-N, N, P, K, Ca, Mg, S, Zn, Fe, Mn, Na, Cu, and B. Molybdenum can be analysed if the equipment is available but the plant tissue concentrations are relatively low and sufficiency criteria are not so reliable. Other methods are better suited for diagnosis. The plant samples (and possibly soil samples if we collect them) will be sent to Australia for analysis.

Appendix 11.3 Soil survey data mean SE and range.

Mean, standard error (SE) and range data for surface soil (0-20 cm) and subsoil (20-40cm) properties for soil samples collected from vegetable cropping systems in Bohol, Leyte, Samar, Davao and Claveria regions The Philippines.

Site	Soil Depth (cm)		pH (1:5 H_2O)	Avail P (mg kg^{-1})	OM (%)	Total N (%)	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Na (cmol kg^{-1})	K (cmol kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
Bohol	0-20	Mean	6.5	20.7	2.6	0.23	22.5	4.4	0.1	0.4	5.8	2.2	39.6	52.0
		Se	0.23	5.6	0.27	0.02	3.5	0.7	0.01	0.06	1.18	0.54	5.2	6.2
		Range	4.49-8.3	0.59-115	1.00-5.66	0.08-0.41	1.64-66.4	0.33-12.6	0.00-0.16	0.02-1.14	0.60-23.4	0.25-11.5	9.75-80.8	12.8-119
Bohol	20-40	Mean	6.6	13.4	1.8	0.20	23.7	4.7	0.1	0.2	4.7	1.9	36.3	38.4
		Se	0.22	3.9	0.26	0.03	3.7	0.8	0.01	0.04	1.06	0.45	5.2	4.1
		Range	5.03-8.19	0.49-75.0	0.23-4.85	0.07-0.63	0-70.7	0.03-13.0	0.00-0.19	0.01-0.71	0.49-19.6	0.31-9.24	8.12-76.3	12.5-86.7
Leyte	0-20	Mean	6.7	39.2	2.4	0.22	59.8	11.7	0.1	0.6	4.8	2.6	25.1	27.6
		Se	0.17	6.8	0.19	0.01	9.6	2.3	0.02	0.07	0.49	0.51	1.6	2.9
		Range	4.77-8.19	1.64-175.	0.67-5.66	0.10-0.42	5.01-176.	1.45-59.9	0-0.49	0.04-1.84	0.91-12.2	0.39-11.2	0.23-40.4	8.32-58.8
Leyte	20-40	Mean	6.8	29.5	2.0	0.19	72.9	13.2	0.1	0.4	4.1	2.1	23.5	24.5
		Se	0.17	5.5	0.17	0.01	15.2	2.9	0.03	0.05	0.39	0.37	1.6	2.6
		Range	4.89-8.19	3.72-152.	0.35-3.63	0.08-0.29	10.1-408.	0.86-69.0	0-0.59	0.04-1.00	1.12-10.6	0.30-10.2	7.42-40.0	7.15-57.7
Samar	0-20	Mean	6.2	17.9	3.0	0.23	22.4	12.2	0.2	0.3	3.8	2.0	28.7	56.8
		Se	0.25	6.9	0.46	0.02	4.6	2.9	0.05	0.06	0.60	0.73	3.6	7.6
		Range	4.85-8.14	0.08-90.9	1.24-6.91	0.15-0.42	2.16-60.6	1.06-38.9	0-0.70	0.05-0.88	0.16-9.62	0.13-11.1	5.66-46.2	9.93-105
Samar	20-40	Mean	6.5	11.1	2.8	0.19	24.6	14.8	0.2	0.2	3.9	1.3	25.4	42.5
		Se	0.23	4.3	0.67	0.02	4.7	3.3	0.05	0.03	0.57	0.28	3.9	5.7
		Range	5.08-8.25	0.61-58.5	0.89-9.64	0.09-0.31	3.42-55.2	3.83-38.5	0-0.51	0.07-0.41	1.32-8.85	0.18-3.24	3.82-46.1	11.0-78.7
Davao	0-20	Mean	6.1	28.8	3.4	0.20	14.7	4.8	0.5	1.5	5.6	2.2	39.8	64.4
		SE	0.21	5.6	0.39	0.02	1.9	1.2	0.11	0.38	0.53	0.44	4.7	6.7
		Range	4.27-8.14	0.07-101	0.4-8.6	0.06-0.44	1.03-42.5	0.11-23.1	0.04-3.05	0.23-10.4	0.1-12.7	0.14-11.5	2.7-109	23-152
Davao	20-40	Mean	5.9	21.2	2.1	0.14	13.8	5.3	0.5	1.5	4.1	1.1	27.2	46.2
		SE	0.22	4.1	0.25	0.01	2.1	1.4	0.07	0.45	0.46	0.17	5.3	6.2
		Range	3.97-8.01	1.18-55	0.17-5.3	0.05-0.31	0.16-44.8	0.07-25.1	0.04-1.56	0.12-11.4	0.4-9.3	0.07-3.3	1.1-116	4.7-137