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1 Acknowledgments

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2 Executive summary

The development of high-value crops for domestic consumption and export is considered a priority for economic development and improved livelihoods in most Pacific Island countries. However, pests and diseases, and a lack of improved varieties adapted to local growing conditions, are the major constraints to vegetable production. The project's broad objective was to build and sustain capacity to develop integrated crop management (ICM) strategies for the sustainable intensification of high-value crop production for export and domestic markets. This was done through improved information sharing: i) by the regular convening of meetings of the project advisory group (PAG) to review project progress and to provide advice on future directions for research and extension activities, ii) field days with farmers (especially in Fiji and Solomon Islands) where new technologies/ crop varieties were demonstrated and iii) the development of a pilot Plant Health Clinic (PHC) program in the Solomon Islands. The PHC program, in which local extension officers were trained as plant doctors, is supported by a mobile app, “Pacific pests and pathogens” that contains 350 fact sheets to aid identification of the most important insect pests and diseases of crops in the Pacific and which also provides management advice.

The project focused not only on developing appropriate ICM solutions to some production problems but doing so in a way that the capacity of local collaborators was enhanced. Specifically, the project investigated the regional status of insecticide resistance in the diamondback moth, a notorious pest that is the target of excessive insecticide use throughout the region. Very high levels of resistance to some insecticides were rerecorded (especially in Fiji) and this necessitated the development of an insecticide resistance management (IRM) strategy designed around the biological insecticide, *Bacillus thuringiensis* (Bt). In collaboration with a local company, a reliable, cost effective Bt product was imported from China and established in the market (prior to the project, this very safe and effective insecticide could not be reliably sourced in the region). The stategy was successfully implemented, resistance levels have declined and evidence to date indicates that Bt is being used sustainably and natural enemy activity in *Brassica* fields has increased in the absence of broad spectrum insecticides. In Samoa, research on the interactions between the egg parasitoid *Trichogramma chilonis* and the large cabbage moth (*Crocidolomia pavonana*) showed that manipulation of the host plant of an alternative host of the parasitoid could facilitate parasitism of the pest. Further work in Samoa showed that jasmonic acid, an elicitor of plant responses to herbivory, could be used to manipulate pest distributions in the field, offering an exciting possibility that pests and natural enemies could be manipulated in this system for improved biological control. ICM research also investigated i) improved Solanaceous crop varieties for quality and market potential, and prospects of extending production seasons, ii) disease management/control and a diagnosis protocol for diseases of Solanaceous crops, and iii)) evaluation of soil management practices to promote sustainable soil health. For disease management and control, five plant activators were evaluated for their ability to suppress fungal pathogens; two of the plant activators had broad spectrum control effects on target diseases of tomato and pepper. A field trial in the Solomon Islands also showed low disease severity following the application of a commercial Phosacid systemic fungicide. To improve diagnoses of foliar diseases causing necrosis on tomato and pepper, a molecular assay procedure was developed using Whatman FTA™ cards. The procedure proved effective and diseases of Solanaceous crops from Taiwan, Fiji and the Solomon Islands were consistently identified using three diagnostic methods: microscopy, isolation and the molecular assay. Field trials to evaluate improved varieties of tomato (n=11) and sweet pepper (n=10) sourced from the WorldVeg genebank in Taiwan were conducted in Fiji, the Solomon Islands, Samoa and Tonga. The trials were completed in Fiji and the Solomon Islands, a total of four open pollinated (OP) tomato varieties (2 in Fiji and 3 in the Solomon Islands) were officially released. For sweet pepper, only one variety was released in the Solomon Islands, while in Fiji, the selection of a variety for official release was delayed. ICM practices evaluated for improved pest and disease management in vegetable production were potting media for tomato seedling production, insect exclusion net, and suitability of protective structures. A long-term soil health trial was also conducted to evaluate soil management practices which included legume rotation and starter solution technology (SST), however, only the legume rotation phase was completed. The good agricultural practices (GAP) and technologies evaluated were also promoted during field days and trainings.

3 Background

The development of high-value crops (e.g. cabbage (*Brassica oleracea*), Chinese cabbage (*Brassica rapa*), tomato (*Lycopersicon esculentum*) and sweet pepper (*Capsicum annuum*) for domestic consumption and export is considered a priority for economic development and improved livelihoods in many Pacific island countries. However, pests and diseases, and a lack of improved varieties adapted to local growing conditions represent serious threats to the production of these and other high value vegetable crops. The considerable economic benefits that successful production of these crops offer has driven previous attempts to intensify production. However, these endeavours have typically not paid adequate attention to the significant research and development that is required to underpin intensification, *viz.* the development and implementation of sustainable pest and disease management strategies and the selection and deployment of varieties adapted to the local environments. Consequently, there have been many failures and any gains have been limited and short-lived. Further, the attempts at intensification have also created serious threats to health and the environment, through inappropriate application of pesticides, which can be particularly damaging to the typically fragile environments of Pacific Island countries. The use of other inputs and degradation of the natural resource base has also exacerbated production problems and contributed further to environmental problems.

In a regional effort to address the development of high value crops, this project aimed to build and maintain capacity to develop ICM strategies for the sustainable intensification of high value crop production for export and domestic markets. The introduction and evaluation of the performance of improved Solanaceous varieties in target countries was complemented by the testing of integrated technologies for crop and pest and disease management. It was anticipated that identification of well-adapted varieties and development of locally relevant sustainable production technologies would lead to tangible, long-term gains. Building the capacity of farmers and national agricultural research and extension staff was considered equally important.

This project began the development of a longer-term program to sustain the development of high-value crops in the region by focusing on building regional and national R&D capacity and working with the Pacific Community (PC) and its national partners. It set out to establish a framework for ongoing research and development through the project advisory group (PAG) and the development of plant information support mechanism. It also sought to begin problem-solving research focused on vegetable production.
By strengthening the supply side of market chains for high-value crops, the project complemented the investments of PARDI in agribusiness development and PHAMA in improved market access. The work on vegetable ICM was designed to be implemented in close collaboration with a PARDI research activity, PRA/2011/03 and with an FAO Technical Cooperation Project (TCP) that strengthened training and implementation in integrated pest management (IPM) and promoted the adoption of alternative technologies to hazardous pesticides. The project also sought to add value to the investment in John Allwright Fellowships (JAF) by integrating returning graduates into problem-solving research.

The research team comprised scientists from the University of Queensland, PC, AVRDC and national government research institutions. The appointment of the “regional IPM coordinator” at PC was critical to the success of the project and it was anticipated at the outset that this would become a long-term position within the organisation, providing ongoing support for crop management research-and-development for the duration of the program and beyond. Significant support for the coordination and implementation of project activities was provided by an AVRDC production agronomist posted to SPC (who worked closely with the IPM scientist at PC, the project leaders at PC and the University of Queensland and the leaders of each of the project’s three major objectives. Together,

this group of scientists formed a strong leadership team for the effective coordination, management and implementation of all project activities.
The project was designed to use participatory research-and-extension methods to strengthen linkages between researchers and farmer associations, other NGOs, private sector input providers and public sector extension services. In so doing it built on previous ACIAR project experiences to achieve broad and sustainable impacts. Positive impacts on several dimensions of livelihoods were anticipated, including improved incomes, better health and nutrition, positive environmental impacts through reduced use of pesticides, and gains in ecological and economic sustainability through more appropriately intensified production techniques. It was also a goal to strengthen the capacity of regional and national research organizations and establish and strengthen links to technical support in Australia and internationally.

Within the broader development goal of improving the livelihoods of smallholders and their communities, the project's aim was to build and sustain the capacity to develop integrated crop management strategies to support the sustainable intensification of high-value crop production for export and domestic markets in the Pacific Islands. This was achieved by addressing three principal objectives:

Objectives:

1. To develop coordination and information-support systems for intensified horticulture (Lead organizations: SPC, with Terra Circle and CABI)
2. To diagnose emerging pest and disease problems and develop management tactics (Lead organizations: UQ with SPC)
3. To develop integrated approaches for intensifying vegetable production (Lead organization: AVRDC with SPC)

4 Objectives

Objective 1: To develop co-ordination and information-support systems for intensified horticulture

Activity 1.1: Establish and sustain Program Advisory Group

Activity 1.2: Plant Health Clinics tested in Solomon Islands

Activity 1.3: Establish advisory committee to edit Solomon Island Pest Fact Sheets and the book Diseases of Cultivated Crops in Pacific Island countries to make relevant for region; make available on line and in hard copy

Activity 1.4: Complete IPM training manuals (extension officer and farmer versions) developed in previous ACIAR initiatives; make available on line and in hard copy.

Activity 1.5: Conduct independent evaluation of PestNet, update website and provide basic infrastructure for improved diagnostic advice in the region

Objective 2: To diagnose emerging pest and disease problems and develop management tactics

Activity 2.1: Insecticide resistance status of DBM determined in Fiji, Samoa, Tonga and Solomon Islands. Insecticide resistance management strategy designed and implemented in Fiji.

Activity 2.2: Evaluation of *Trichogramma chilonis* as a biological control agent for the large cabbage moth.

Activity 2.3: Cultural control methods for the management of *Nisotra basselae* in Solomon Islands developed and tested

Activity 2.4a: Evaluation of elicitors insect resistance in Brassica crops

Activity 2.4b: Evaluation of biochemical elicitors of pathogen resistance in Solanaceous crops

Activity 2.5: Develop improved techniques for disease diagnosis and monitoring in targeted vegetable crops

Activity 2.6: Assessment of susceptibility of four varieties of potato imported from NZ to bacterial wilt *Ralstonia solanacearum*.

Objective 3. To develop integrated approaches for intensifying vegetable production (Lead organization: WorldVeg with SPC)

Activity 3.1: Use of standard screening procedures (developed in PC2005/077) to field evaluate improved varieties of Solanaceous crops for quality and market potential, as well as the prospects of extending production seasons in Fiji, the Solomon Islands, Samoa, and Tonga.

Activity 3.2: Field evaluation of ICM practices (including better-adapted varieties, improved potting mix formula, simple drip irrigation kits, protective structures, insect exclusion technologies, and the integration of bio-rational pesticides) for improved pest and disease management in year-round vegetable production in Fiji, the Solomon Islands, and Samoa

Activity 3.3: Field evaluation of soil management approaches (including use of biochar, legumes as rotation crops, and balanced fertilization) to promote sustainable soil health.

Activity 3.4: Research station field days and on-farm demonstrations to promote adoption of technologies.

5 Methodology

Objective 1: To develop co-ordination and information-support systems for intensified horticulture

Activity 1.1: Establish and sustain Program Advisory Group

The project advisory group (PAG) was established in 2012 at the first project meeting held at Sigatoka research station in Fiji. The group, which consisted of key personnel from collaborating countries, met consistently throughout the project as planned. Annual meetings lasted for 5 days and they were always very well attended by key project personnel from Australia, Fiji, Samoa, Solomon Islands, Tonga and AVRDC. Annual PAG meetings were held as planned at: Sigatoka Research Station, Fiji in 2012 (organisers MAF-Fiji/ SPC); Vaini Research Station, Tonga in 2013 (organisers MAFFF-Tonga/ SPC); Nu'u Crops Research Station, Samoa in 2014 (organisers MAFF-Samoa/ SPC); Honiara, Solomon Islands in 2015 (organisers MAL-Solomon Islands/ SPC) and at Sigatoka Research Station, Fiji in 2016 (organisers MAF-Fiji/ SPC). In addition to HORT/2010/090 funded PAG meetings the project benefited from the close relationship with the FAO-TCP on pesticide reduction and IPM promotion, allowing an additional 3 PAGs to be integrated into the PAG timetable throughout the life of the project. The final PAG meeting at SRS in July 2016 also served as the forum for the end of project review. In all PAG meetings, agreed project activities were reviewed and detailed work-plans for the project were collaboratively formulated and agreed upon. From June 2014, the closely aligned project HORT/2010/065 also benefitted from the PAG framework and project members from PNG became fully integrated members of the group.

Activity 1.2: Plant Health Clinics tested in Solomon Islands

In its early phase, the pilot Plant Health Clinic (PHC) project was run in close collaboration with Dr Eric Boa (CABI), who introduced the concept to the region in a training workshop, "How to Become a Plant Doctor" held in Solomon Islands 21-24 May, 2012. The workshop was attended by the project coordinators from Fiji, Samoa, Solomon Islands and Tonga. Participants from Solomon Island included representatives from MAL (8 participants), KGA (5 participants) and other local NGOs (8 participants), in total 24 trainees attended the workshop. Following the training a total of 12 clinics were run May-December 2012. In February/ March 2013 a 5-day workshop was run at KGA, Burns Creek by Grahame Jackson (16 attendees; 6 MAL, 7 KGA, 3 other local NGOs) focused on further training of plant doctors, specifically the running of PHCs, two more clinics were run as part of the extended training and two more were run in March/ April 2013.

In September 2103, Dr Jeff Bentley spent 3 weeks in Solomon Islands with the local PHC team to independently review the PHC program. The close collaboration between countries that was engendered by the PAG resulted in Fiji, Samoa and Tonga all expressing a strong desire to develop national PHC programs; this was facilitated, although as this was not budgeted only limited extra training and PHC activities could be conducted.

Activity 1.3: Establish advisory committee to edit Solomon Island Pest Fact Sheets and the book Diseases of Cultivated Crops in Pacific Island countries to make relevant for region; make available on line and in hard copy.

The advisory committee was formed from representatives of collaborating countries at the project inception workshop in 2012 and a plan to edit existing facts sheets and produce new fact sheets that were required nationally and/ or regionally was agreed to. Members of the committee again confirmed their commitment to help edit fact sheets at the PAG in Honiara, Solomon Islands in July 2015. However, help was limited, and Grahame Jackson did this work single-handed. 10 bound copies of the Farmer factsheets (90 factsheets) and 10 copies of the Extension factsheets (90 factsheets) were printed for the initial PHC training workshop in Solomon Islands (May 2012). These, and an additional 350 fact sheets developed during the project are available online at adder.cbit.uq.edu.au - /project_files/Solomon Islands/Fact sheets/

The PAG decided that rather than producing hard copies (which are expensive, bulky and impossible to update) a better approach to making all of this information widely available would be to produce an app containing all the fact sheets (plus additional resources) that could be updated as more fact sheets became available and as new information on the management of the pests and diseases emerged. The “Pacific Pests and Pathogens” app was developed in collaboration with Identic Ltd. and version 1 was published for free download (Google store and iTunes) in 2014; 5 updates have since been produced and all additional material has also been made available online (adder.cbit.uq.edu.au - /project_files/Solomon Islands/Fact sheets/). Savings in publication costs from elsewhere (see immediately below), allowed purchase of 9 Samsung Galaxy Tablets (2 for each collaborating national ministry, 1 for SPC).

Activity 1.4: Complete IPM training manuals (extension officer and farmer versions) developed in previous ACIAR initiatives; make available on line and in hard copy.

The material received from each country is available online (adder.cbit.uq.edu.au - /project_files/). During the project IPM extension material development focused on the further development of pest and disease fact sheets for the “Pacific Pests and Pathogens” app. These fact sheet, which were developed by Grahame Jackson, contain information on IPM relevant to each of the pests and diseases that it covers.

Activity 1.5: Conduct independent evaluation of PestNet, update website and provide basic infrastructure for improved diagnostic advice in the region.

Professor Geoff Norton (QBIT) conducted an independent evaluation of Pestnet. The report was presented at the PAG in Tonga in September 2013.

Objective 2: To diagnose emerging pest and disease problems and develop management tactics

Activity 2.1: Insecticide resistance status of DBM determined in Fiji, Samoa, Tonga and Solomon Islands. Insecticide resistance management strategy designed and implemented in Fiji.

Regional status insecticide resistance in DBM.

The susceptibility of field populations of DBM to commonly used and recently introduced selective insecticides was monitored throughout the project in Fiji (2012-2017), Tonga (2013-2015) and Samoa (2013-2015) (See Table 5.1 below). Head cabbage or Chinese cabbage crops were hand searched and large larvae and pupae were collected and taken back to the laboratory. A minimum of 50 individuals was collected per site, but typically >>100 individuals were collected. Insects from a single site were transferred to an oviposition cage to mate and lay eggs. Typically, second instar larvae from the next generation of insects was used in tests of the susceptibility of the population to a range of given insecticides but in some cases egg numbers produced were low and numbers had to be built up over one or more further generations before they could be tested in leaf dip bioassays (see Atumurirava et el., 2016, for detailed methodology). In all cases the susceptibility of the field population was compared to that of the Waite population, standard insecticide susceptible DBM population that has been kept in the lab for more than 200 generations. For any given field population, the resistance ratio (RR) to a given insecticide was calculated by dividing the LD_{50} of that insecticide against that population by the LD_{50} of the insecticide against the Waite population. As is considered the norm, when RR>10 a significant decrease in the susceptibility of the population to the given insecticide was considered to have occurred.

Table 5.1 Collections of diamondback moth for insecticide resistance monitoring prior and subsequent to the introduction of the Insecticide Resistance Management (IRM) strategy in Fiji in July 2014

Country	Date	Field populations tested (Generation)*	Insecticides (active ingredients) tested
Fiji	November 2012-February 2013	Sigatoka Upper valley (F_1); Sigatoka Mid valley (F_1); Sigatoka Lower valley (F_3)	Deltamethrin, indoxacarb, lufenuron, Bt, cholortraniliprole.
	August-September, 2013	Bulileka (F_1); Korotari (F_1)	Deltamethrin, indoxacarb, lufenuron, Bt, cholortraniliprole.
	June-September, 2014	Bulileka (F_1); Korotari (F_1); Sigatoka Lower valley (F_1); Sigatoka Lower valley (F_1)	Deltamethrin, indoxacarb, lufenuron, Bt, chlorotraniliprole, abamectin
	September 2015	Sigatoka Lower valley- West Bank (F_3); Sigatoka Lower valley- East Bank (F_3)	Abamectin, indoxacarb, lufenuron, Bt, cholortraniliprole.
	September 2016	Sigatoka Lower valley (F_2); Korotari (F_2)	Abamectin, indoxacarb, lufenuron, Bt, cholortraniliprole.
	September 2017	Sigatoka Lower valley- West Bank (F_3); Sigatoka Lower valley- East Bank (F_2)	Abamectin, indoxacarb, lufenuron, Bt, cholortraniliprole.
Tonga	September, 2013	Veitongo (F_1)	Deltamethrin, indoxacarb, lufenuron, cholortraniliprole.
	September, 2014	Vaini Kava (F_1); Vaini Laikau (F_1); Matahau (F_1); Folaha (F_1)	Deltamethrin, indoxacarb, lufenuron, cholortraniliprole, deltamethrin-pirimiphos-methyl, Bt.
	July, 2015	Vaini (F_1)	Bt.
	December 2015	Vaini (F_1)	Abamectin, indoxacarb, lufenuron, cholortraniliprole.
Samoa	October-November 2013	Aukuso (F_1); JW (F_1); Nu'u (F_1)	Deltamethrin-pirimiphos-methyl, Bt, lufenuron, cholortraniliprole.
	September, 2015	Aukuso (F_2); China (F_2); Faleasiu (F_2); Tanumalala (F_2)	Deltamethrin-pirimiphos-methyl, Bt, lufenuron, cholortraniliprole.

*Generation post collection and rearing in the lab that was tested for susceptibility to insecticides

Design and implementation of Insecticide Resistance Management (IRM) strategy in Fiji.

The insecticide resistance management (IRM) strategy was based on the principles advocated by the Insecticide Resistance Action Committee (IRAC) (www.irac-online.org). Fundamentally the strategy is based upon the rotation of insecticides with different modes of action in a manner that minimises the probability that individuals of successive generations will be exposed to insecticides with the same mode of action. When the IRM strategy for DBM was being designed for Fiji we faced three significant constraints: i) it was a project goal to promote and implement IPM strategies for the management of Brassica pests (this precluded the use of many of the insecticides available and widely used in Fiji at the time), ii) DBM field populations in Sigatoka exhibited resistance to deltamethrin and the recently introduced selective insecticide Prevathon (Chlorotraniliprole) and iii) farmer access to selective insecticides was limited and they had no access to the IPM compatible, safe and highly selective insecticide Bt. Bt is considered fundamental to sustainable management of DBM (Furlong et al., 2013) and the project team considered this fundamental to the ongoing safe management of the pest and hence the IRM strategy. In order to ensure that Bt became reliably available in Fiji (and later the region) we worked closely with a local retailer, AgChem Fiji. In partnership with AgChem Fiji the project facilitated the importation, field testing (to satisfy Fiji Ministry of Agriculture requirements), registration, packaging and promotion of a Bt product from China (this had previously been successfully used in ACIAR project HORT/2002/062 in DPRK (Furlong et al., 2008)) as a central component of the IRM strategy. The basic principles of the IRM strategy that was developed and implemented are:

- selective insecticides are used in "windows" that are of duration < 1 DBM generation (≈ 18 days) (residual activities of insecticides are taken into account)
- available insecticides with different modes of action are alternated between these "windows"
- of the insecticides available in Fiji in 2014, Steward (indoxacarb), Match (lufenuron), Multiguard (abamectin), AgChem Bt (Bt) and Prevathon (chlorotraniliprole) were considered appropriate for incorporation into the overall

IPM/ IRM strategy but pyrethroid and organophosphate insecticides were not and were excluded.

AgChem Bt was launched in Fiji in July 2014 and was sold with a project developed leaflet on how it should be applied in a manner consistent with the basic rules of the IRM strategy; the launch was accompanied by a series of "Pesticide Forums" across Viti Levu and Vanua Levu.

Laboratory validation of the IRM strategy.

The IRM strategy was tested in the laboratory by measuring the susceptibility of a field population of DBM that was highly resistant to deltamethrin to a range of insecticides using the leaf dip method (Atumurirava et al., 2016). The original population was split into 4 sub-populations, each of which was exposed to one of the following treatments:

i) repeated exposure to deltamethrin for 5 generations (this is typical of current practice by many farmers in Fiji and the region).
ii) application of the IRM strategy (alternation of selective insecticides between each generation).
iii) repeated exposure to Bt for 5 generations.
iv) no exposure to any insecticide for 5 generations.

After 5 generations, the susceptibility of the different populations to all insecticides was measured again. As a control, the susceptibility of the Waite population to the different insecticides was monitored at the start and at the end of the experiment.

Activity 2.2: Evaluation of *Trichogramma chilonis* as a biological control agent for the large cabbage moth.

Basic biology of interaction between *T. chilonis* and large cabbage moth (LCM) and host range status determined

The parasitoid was reared in large cabbage moth (LCM), diamondback moth (*Plutella xylostella*) and Monarch butterfly (*Danaus plexippus*) eggs in the laboratory and parasitoid survival, sex ratios and other bionomic factors in were measured. An extensive literature search was conducted to determine the potential host range of *T. chilonis* and this was complemented by studies on the host range of the Samoan *T. chilonis* population in the field. Preliminary field- sampling studies showed that, in addition to eggs of LCM, eggs of the Angel moth (*Nyctemera baulus alba*), the Common Eggfly (*Hypolimnas bolina)* and the Fruit-piercing moth (*Eudocima phalonia*) were parasitised by *T. chilonis*. Eggs of these species were collected from cabbage crops (LCM and Eggfly) and surrounding vegetation (Angel moth from the weed *Crassocephalum crepidioides* and fruit-piercing moth from the tree *Erythrina variegate*) in surveys on Upolu and Savai'i. When possible, multiple samples of each species of host egg were collected from each site (within 100m) so that molecular tests to confirm the identity of the parasitoids could be conducted and the gene flow between *T. chilonis* (using ITS and CO1 markers developed specifically for the project) parasitising different host species could be investigated. The eggs were taken back to the laboratory, transferred to gelatine capsules and incubated until they hatched, or a parasitoid emerged. Parasitoids were then transferred to single vials containing 95% ethanol and stored in a freezer until they were subject to genetic analysis.

Suitability of *T. chilonis* for integration into biological control programs elsewhere in the Pacific understood and mass-rearing protocols for *T. chilonis* established.

Biological control is an essential feature of IPM programs which can be designed to maximize the impact of biological control agents on pest populations. In Brassica production systems biological control coupled with strategic application of selective insecticides has proven successful (Furlong et al. 2004, 2008). In order to maximise the efficacy of endemic biologicals control agents available in an IPM program, field experiments were conducted in both Fiji and Samoa to test the efficacy of using a combined Bt intervention threshold based on the DBM density in a crop and the proportion of plants infested by LCM. The DBM densities tested were dynamic and changed with crop phenology; tolerable DBM density was lowest (2.5 larvae plant^{-1}) when the crop was at the vulnerable cupping stage, intermediate when plants were small (5 larvae plant^{-1}) and highest after heading (20 larvae plant^{-1}), when plants can tolerate significantly higher densities of DBM. Different LCM thresholds were tested at crop infestation levels of 10, 20 and 30% of plants (Appendix 1). In a series of experiments in Fiji and Samoa, experimental crops were managed using the combined Bt intervention threshold and Bt was applied when the threshold was exceeded, these crops were compared with conventionally managed crops which were treated weekly with broad-spectrum insecticide in order to replicate typical farmer practice. The impact of *T. chilonis* on LCM populations was investigated in "natural enemy exclusion" experiments in which the fate of experimental LCM eggs placed on to potted cabbage plants in the field was investigated when plants were completely covered with fine mesh in order to prevent natural enemies (*T. chilonis*, other parasitoids and predators from attacking eggs) or covered with fine mesh to replicate the environmental conditions that the plants/ eggs were exposed to but which allowed natural enemies access to the eggs. In an experiment to investigate the effect of alternative host (=*N. baulus alba*) eggs on the *T. chilonis* parasitism rate in LCM eggs, the host plant of *N. baulus alba, C. crepidioides,* was inter-planted with cabbage plants in a crop at Nu'u Crop Research Centre, Samoa (See Figures 7.6f and 7.7 below) and parasitism monitored in the alternative host and LCM eggs over a period of 2 months. As our work showed that management of the endemic natural enemies in the field was key to success, no mass rearing program for the release of *T. chilonis* was developed; rather resources were diverted to understanding how we could best conserve and manipulate natural enemies in the field.

Activity 2.3: Cultural control methods for the management of *Nisotra basselae* in Solomon Islands developed and tested

Although several field experiments were set up, monitoring of the experiments proved difficult in Solomon Islands and at the PAG in 2015 it was decided that no further resources would be channelled to these activities.

Activity 2.4a: Evaluation of elicitors insect resistance in *Brassica* crops

Plant responses to herbivory and insect attraction and oviposition.

The effects of post-herbivory feeding interval on attraction of DBM to common cabbage (*Brassica oleracea*) and Chinese cabbage (*B. rapa*) was investigated by introducing 15 larvae (2nd-instar) onto undamaged plants. In one group of plants for each species (n = 10), larvae were allowed to feed freely on the plant for 6 h, whereas in other, larger groups (common cabbage, n = 250; Chinese cabbage, n = 150), larvae were allowed to feed freely on the plant for 24 h. Infested common cabbage plants and infested Chinese cabbage plants were maintained in a separate controlled environment rooms. After 6 h, the first group of plants was used immediately to test the pre-alighting responses of female DBM in olfactometer studies (see below). For the remaining infested plants, all larvae and any exuviae and frass were carefully removed from plants after 24 h, while the undamaged plants were held in further separate rooms under identical environmental conditions. For each plant species, individual female moths (2-3 days post eclosion, mated, fed, and with no previous exposure to host plants) were tested against an undamaged plant and an herbivore-damaged plant at different times (6h, 1, 2, 3, 4, 5, 6 and 7 days) after herbivory in y-tube olfactometer tests (see Ang et al 2016 for detailed methods). Temporal changes in post-alighting oviposition preferences of DBM between undamaged plants and herbivore-damaged plants were tested in ventilated oviposition cages (40 x 40 x 40 cm). Each day for up to 7 days, where day 1 was 0 h from larval removal from damaged plants, 3 adult female DBM (reared as above) were introduced into a cage. Each cage contained one undamaged plant and one damaged plant of the same species after a given period post-herbivory; plants were placed at diagonally opposite corners of each cage such that the distance between the centres of both pots was at least 30 cm. Females were released in the centre of the cage and remained there for 24 h. after which time the plants were systematically inspected for eggs and the numbers recorded.

Effectiveness of plant responses to herbivory for manipulating insect distributions

A field experiment was conducted in a plot of 120 common cabbage plants (7-leaf stage), at Nu'u Crop Research Station, Samoa in July 2015. Intact potted common cabbage plants (n = 8), and potted common cabbage plants treated with exogenous Jasmonic acid (JA) (n = 6) (JA is a chemical elicitor of plant defence responses which has been shown to replicate the effects of insect herbivory in *Brassica* plants, see Ang et al 2018 for detailed explanation and methods) were randomly positioned within the cabbage plot. Each day for four consecutive days after they were placed in the field, each potted plant was carefully examined and the number of eggs on each leaf and the stem of each plant was recorded daily.

Plant responses to herbivory and the attraction of natural enemies

In order to better understand the behaviour of natural enemies in response to herbivore induced volatiles in crop plants, the effect of previous experience on the responses of the DBM parasitoid *Diadegma semiclausum* Hellén (Hymenoptera: Ichneumonidae) to common cabbage and Chinese cabbage host plants was investigated in Y-tube olfactometer bioassays (see Furlong et al., 2018 for detailed methods). Test insects were introduced to the end of the Y-tube and choice was considered made once a test insect breached the 2.5 cm mark up an arm of the Y-tube. For each pairwise combination of plant treatments, fresh female parasitoids were used until 30 individuals had responded.

Activity 2.4b: Evaluation of biochemical elicitors of pathogen resistance in Solanaceous crops

Plant activators (or elicitors) induce defence responses in plants, which can prevent or suppress pathogen infection. Glasshouse experiments were conducted in 2013 and 2014 to assess the efficacy of neutralized phosphorous acid (1000 ppm), BION™ (100 ppm), ReZist™ (5000 ppm), potassium silicate (600 ppm), and chitosan (500 ppm) against selected tomato (late blight, early blight, black leaf mould, grey leaf spot, southern blight, damping-off, and bacterial spot), and pepper diseases (Phytophthora blight, southern blight, damping-off, and bacterial spot). Cultivars with known levels of susceptibility to each disease were used. Plant activators were sprayed on leaves of tomato and pepper seedlings until run-off. After three days, the plants were inoculated with respective pathogen for each disease. Data on foliar disease symptoms were then recorded.

In November 2016, a replicated field trial was conducted at Betikama school farm, Honiara, Solomon Islands to test the efficacy of a locally available commercial Phosacid systemic fungicide known as *Yates Anti Rot®*, against tomato foliar diseases under local growing conditions. Two WorldVeg tomato varieties (Rose's Choice and MAL Cherry) officially released in Solomon Islands under the ICM project, and a local variety (Local Red) were evaluated. The four spray treatments applied (20 plants/variety) were (i) Anti Rot (200g/L), (ii) Bikpela (720g/L), a locally available fungicide, (iii) Anti Rot + Bikpela, and (iv) Control (no spray). The experimental design was Factorial Randomized Complete Block Design (RCBD) with four replications. Data on disease severity was recorded using a scale rating of 1 to 6 (1 = 15% leaf area affected and small leaf lesions; 2 = 6-15% leaf area affected and necrosis-restricted leaf lesions; 3 = 16-30% leaf area affected and coalescent leaf lesions; 4 = 31-60% leaf area affected and edge-expanding leaf lesions; 5 = 61-90% leaf area affected and drying leaf lesions; and 6 = 91-100% leaf area affected, leaves blighting, extensive stem damage, and/or plant dead). Yields were assessed by recording cumulative yield (total and marketable) from the first harvest until the end of the trial.

Activity 2.5: Develop improved techniques for disease diagnosis and monitoring in targeted vegetable crops

Development of paper-based protocol for molecular diagnosis of foliar diseases

i) Development of a procedure for molecular diagnosis of tomato foliar diseases

Foliar diseases with brown necrotic lesions (early blight, target spot, grey leaf spot, and bacterial spot) are common in tomato crops in the region. Due to the similarity of symptoms, laboratory assays are usually required for accurate diagnosis. In 2014, a study conducted in Taiwan validated the use of FTA™ card as a molecular assay for diagnosing

these diseases to support remote diagnosis. The *Whatman FTA™* card was adopted as a simple and effective way to capture and preserve DNA from diseased samples. During the rainy season in August 2014, samples were collected from two tomato fields (one each in Lona and Tungfu villages) near Hsinyi, Nantou, Taiwan. Twenty samples per lesion type were collected and examined for spore morphology and bacterial oozing. Two pieces of leaf tissue (ca. 1 mm^2) were cut out from each lesion for isolation and DNA extraction. For DNA extraction, leaf tissue was ground with 70 percent alcohol and applied to the FTA™ card. A disc was then punched out from the sample area of the FTA™ card was used for polymerase chain reaction (PCR) to amplify the internal transcribed spacer (ITS) region using primers ITS4/5. The ITS sequence was obtained by direct sequencing of the PCR products. Identification of fungal pathogens was determined based on the sequence BLASTn search results. The samples which could not be identified based on the ITS sequence were re-amplified with *Xanthomonas*-specific primers Xan7/X-gumD-fw.
Field surveys conducted in Solomon Islands and Fiji in November and December 2016 used a protocol developed at WorldVeg HQ (Appendix 2) to collect DNA from necrotic spot(s) on tomato leaves so that the causal organisms of the diseases could be identified. Surveys employed a stratified-systemic sampling plan to determine the incidence of leaf spot lesions in the field. Based on visual symptoms, the lesion type found in the field was classified, and four tomato leaves with the targeted lesion type were collected from different sites within the field. A single lesion was cut from each leaf and the sample (0.1 x 0.2 cm) was submerged in 150µl 70% ethanol in a 1.5mL micro centrifuge tube before it was ground up. A drop of the ground tissue mixture was then transferred to the FTA™ card. A single FTA™ card was used to collect four samples from each legion type. The number/code of the disease sample was written in the appropriate “Sample ID” box on the cover of the FTA™ card which was folded, and the sample allowed to dry for two hours. Dried cards were stored in a foil bag and kept in air-tight containers with silica gel at room temperature until samples were sent to WorldVeg HQ for processing. Extracted samples from diseased tomato leaves in Solomon Islands and chilli samples from Fiji were sent for identification in November 2016 and January 2017 respectively.
ii) Improvement of molecular diagnosis of Colletotrichum *species causing pepper anthracnose*
A paper-based protocol for molecular diagnosis of *Colletotrichum* species associated with pepper anthracnose using FTA™ cards was developed at WorldVeg HQ in 2012 (Appendix 3). The key steps of the protocol include homogenizing mycelium or diseased tissue with 70 % ethanol, two rounds of PCR (first with ITS4/ITS5 followed by ITS4/C1), and digestion with three restriction enzymes to obtain ITS-RFLP (restriction fragment of length polymorphism of internal transcribed spacer of ribosomal RNA genes) patterns specific for each species. The classical (morphological) method and the ITS-RFLP method were used to identify a total of 13 isolates collected from diseased chilli pepper fruits from Fiji in 2012 and samples from sweet pepper with anthracnose symptoms received from Solomon Islands in 2013.

Objective 3. To develop integrated approaches for intensifying vegetable production (Lead organization: WorldVeg with SPC)

Activity 3.1: Use of standard screening procedures (developed in PC/2005/077) to field-evaluate improved varieties of Solanaceous crops for quality and market potential, as well as the prospects of extending production seasons in Fiji, the Solomon Islands, Samoa, and Tonga.

Development of variety evaluation procedures for tomato and capsicum

Prior to conducting variety field trials variety evaluation, protocols for trial procedures, experimental design and data collection for tomato, capsicum and chilli (Appendices 4, 5, and 6) respectively) were developed between 2012 and 2014.

Evaluation of improved OP tomato and sweet pepper varieties *i) Tomato variety evaluation trials*: Evaluation field trials for tomato varieties (Appendix 4) were conducted in the Solomon Islands, Fiji, Samoa and Tonga from 2012 to 2015. However, trials in Samoa and Tonga did not continue beyond the completion of confirmation and observation trials (Figure 5.1). A total of 11 improved breeding lines tomato from WorldVeg HQ genebank were evaluated in Fiji and Solomon Islands over three regular cropping seasons from May to October each year. At the end of the observation, confirmation, and promotion stage of each trial, varieties with poor field performance, low yield or unacceptable taste to local consumers were eliminated, while the best performing varieties were selected for the next trial. Upon completion of the promotion phase, a variety for official release by the local Ministry of Agriculture in Fiji and Solomon Islands was then selected after appropriate taste testing was completed.

ii) Sweet pepper variety evaluation trials: Evaluation field trials for OP sweet pepper varieties (Appendix 5) were conducted in the Solomon Islands, Fiji and Samoa from 2012 to 2016. However, an error in labelling of varieties in Samoa meant that studies there stopped at the completion of the confirmation trial stage in 2014. Ten WorldVeg improved sweet pepper breeding lines were evaluated in the Solomon Islands and Fiji and 5 of these were also evaluated in Samoa; all evaluations were conducted over three regular cropping seasons. In 2015, three field trials were completed in Fiji, however, an adopted variety was not selected because the Ministry of Agriculture (MOA) required the varieties to be tested at different locations in Fiji before a variety could be selected. In Solomon Islands, a sweet pepper line was selected after the completion of three field trials and the variety was officially released in March 2017.

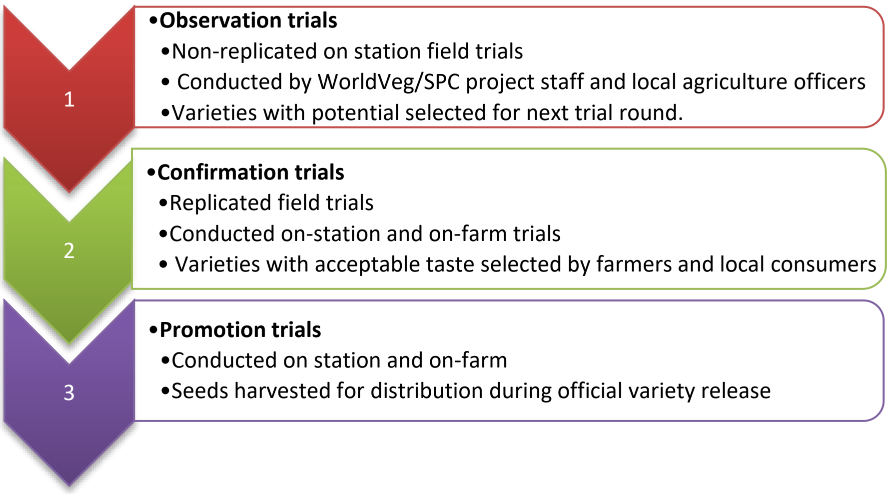

Figure 5.1. Variety selection protocol adopted by the project

<u>Identification of adapted tomato varieties for extending the production season in Fiji</u>

An off-season tomato trial was conducted following the trial protocol for regular season variety evaluation (Appendix 4) at Sigatoka Research Station from October 2014 to February 2015. Seven varieties were evaluated (three WorldVeg lines (OP varieties CLN 3212A and CLN 2585D, hybrid variety CLN 3575-F1), three Known-You hybrid varieties (Grace, Sensation, and King Kong #2) and compared with Raising Sun #2 as a local check. The trial (RCBD design) consisted of three replicates of 20 plants of each variety. Urea was applied after 3 and 6 weeks after transplanting, and NPK was applied at flowering and after the first harvest. The crop was flood irrigated twice a week in the first few weeks and once a week thereafter. The crop was maintained with standard management practices of pruning side shoots, lower leaves and fruit clusters. Weekly monitoring for pest and diseases was conducted during the cropping season. Mancozeb and Kocide were applied fortnightly against foliar diseases while Sunchloprid and *Bacillus thuringiensis* (Bt) were applied, when required, to control flea beetle and tomato fruit borer. Marketable yield data was recorded during harvest.

Evaluation of tomato grafting for off-season production in Solomon Islands and Fiji.

In 2014, grafting technology was evaluated as a means of extending tomato production into the wet season in Solomon Islands. Two tomato scions (CLN 2585D, a high yielding WorldVeg OP line and Grace, a hybrid cultivar of Known You Seeds) were grafted onto three WorldVeg flood-tolerant rootstock eggplant varieties (EG 195, EG 190, and EG 203) which have resistance to several soil borne diseases including bacterial wilt, nematodes and fusarium wilt. A total of 6 treatments were evaluated (Table 5.1) and compared with the non-grafted seedlings of both tomato varieties (T1 and T2).

Table 5.1. Different combinations of tomato scions and WorldVeg eggplant rootstocks evaluated in grafting trials in the Solomon Islands, 2014

	Tomato Scions	
Eggplant rootstocks	**CLN 2585D**	**Grace**
Non-grafted	Non-grafted CLN 2585D (T1)	Non-grafted Grace (T2)
EG 190	EG 190 + CLN 2585D (T3)	EG 190 + Grace (T4)
EG 195	EG195 + CLN 2585D (T5)	EG 195 + Grace (T6)
EG 203	EG 203 + CLN 2585D (T7)	EG 203 + Grace (T8)

Following the successful grafting evaluations, a training workshop on the entire procedure (from grafting to field management of grafted seedlings), was conducted for Ministry of Agriculture and Livestock (MAL) staff, Rural Training Center (RTC) students, and farmers to widely promote adoption of the technology. A total of 30 participants attended the training. In Fiji, only hands-on grafting sessions were conducted for ICM project staff and interns in 2014 and 2015. Grafted seedlings were placed in a locally constructed healing-chamber; however, the survival rate was low and preliminary grafting field trials could not be conducted.

Activity 3.2: Field evaluation of ICM practices for improved pest and disease management in year-round vegetable production in Fiji, the Solomon Islands, and Samoa.

Understanding current practices and constraints on crop management, postharvest and marketing

A farmer survey was conducted in target communities in Fiji in September and October 2012 to improve understanding of current practices for and constraints to crop management, postharvest and marketing. Surveys were conducted in villages in the Sigatoka Valley (Nawamagi, Lokia, Nabitu, Raunitoga; Qereqere and Barara), the Cane Coastal Area (Biausevu, Komave and Namatakula), and Koronivia (Koronivia Road) on Viti Levu. Sigatoka Valley was selected because it is the main vegetable production area in Fiji, accounting for an estimated 80% of total production. The Cane Coastal Area and Koronivia were selected as they had markets and communities willing to join the Participatory Guarantee System (PGS) project activity. The survey targeted existing farmer groups in the villages. Group leaders were notified prior to the surveys and invited to participate. A structured questionnaire was used to collect data on tracking information, socio-demographic information, farm information, production information (up to three of the most important vegetable crops on each farm), market information, capital and socio-economic status, and training and extension needs. The survey team consisted of four enumerators from SPC and WorldVeg (Suzanne Neave), Govind Raju, Nitesh Nand, and Aloesi Hickes) assisted by MOA staff (Makereta Rasuka, Ajay Chand, Sakeasi Ralulu, and Unaisi Remudu). Each household was visited by a three-person team (two enumerators and one MOA staff). The results of the survey were then consolidated and reported (Appendix 7).

Evaluation of improved potting formula for tomato seedling production in Fiji

Survey results showed that smallholder vegetable farmers in the Sigatoka Valley mostly used field soil beds to raise seedlings. This practice may result in seedlings with high disease incidence and poor growth after transplanting. In comparison, the plug tray system has been found to be effective in raising robust seedlings (Fink et al., 2013). Evaluation of different potting media for plug trays was conducted to identify a suitable mixture using locally available materials for tomato seedling production. Two common substrates, soil and compost, were mixed with various materials in the trial conducted at Sigatoka Research Station from April to May 2014. The performance (height, number of leaves and root length) of tomato seedlings (Raising Sun #2) in six different mixes of soil, compost, coconut husk was investigated in a RCBD trial with 3 replicates. Data was recorded 13, 15, 17 and 23 days.

<u>Determination of suitability of protective structures for extending production season (in wet areas)</u>

This activity linked with the ACIAR Pacific Agribusiness Research for Development Initiative (PARDI) project and aimed to extend the production of Solanaceous, Brassica and Cucurbit crops, and herbs during the off-season in Fiji by constructing protective cropping structures. MOA staff and farmers were trained in production methods utilizing the protective structures. The project also conducted variety trials on the selected crops. The activities mainly focused on demonstration of cropping techniques (pruning, trellising, and irrigation systems) with the aim of encouraging farmers to adopt the practices.

<u>Verification on the use of insect exclusion nets and Bt application as a component of Brassica Integrated Pest Management (IPM) on small farm holdings</u>

Insect netting can be effective against insect pests such as aphids, diamondback moth and leaf miners. Earlier studies in the Solomon Islands identified that an insect exclusion net MikroKlima® (called veggie net) could control cabbage insect pests resulting in improved yields and quality (Neave et al., 2011). In 2014 and 2016, two field trials were conducted in Fiji (Barara, Sigatoka Valley; July-September 2014) and the Solomon Islands (Betikama School, May- August 2016) to further evaluate the efficacy of integrating "veggie net" with Bt. In each country, two field trials were conducted, the treatments were (i) net covering over the plot from transplanting to post-cupping, (ii) net covering over the plot from pre-cupping to post-cupping, (iii) Bt application on uncovered plants/plots, and (iv) control (uncovered plots and no Bt application). Each treatment was replicated 3 times with 20 plants per plot planted in two rows. Monitoring was done at intervals of seven days. Field trials were successfully completed and data for analysis was collected on insect pest numbers, and yield (measured as total marketable and non-marketable weights of cabbage heads harvested).

<u>**Activity 3.3:** Field evaluation of soil management approaches (including use of biochar, legumes as rotation crops, and balanced fertilization) to promote sustainable soil health.</u>

<u>Determination of current status of soil health in pilot sites</u>

The health of soil is defined by its physical, chemical and biological processes and functions. Healthy agricultural soil requires a holistic approach to its management. Concurrent with the farmer survey, a soil health survey was conducted in targeted communities in September and October 2015 (Table 5.2). A total of 15 survey locations were identified, including 13 farms in target communities. Measurements of soil health indicators were collected and following analysis, management practices for improving or sustaining soil health based on the measured constraints were recommended.

<u>Evaluation and identification of suitable legume crops as rotation crops</u>

Three legume species, mucuna bean (*Mucuna pruriens*), cowpea (*Vigna unguiculata*) and yard long bean (*Vigna sesquipedalis*) were selected as rotation crops for a long-term soil health field trial at Sigatoka Research Station. Mucuna bean has been introduced to Fiji to improve soil health for taro production due to its fast growth, high accumulation of biomass, and deep roots. Cowpea and yard long bean are commonly grown in Fiji and could provide additional income for farmers as well as improving the soil. Vegetable crops, in general, have high nutrient demands in a relatively short growing period, therefore an additional boost of nutrients is required; these could be provided by legume crops, when used in rotation with vegetables.

Table 5.2. Soil sample index (ID), name of respondent, village name, and location of farms selected for the survey

Soil ID No.	Respondent name	Village	Location
S1	Dhirend Prasad	Barara Settlement	Sigatoka (West bank)
S2	Rajen Sharma	Barara Settlement	Sigatoka (West bank)
S3	Inoke Momonakaya	Namatakula	Cane Coastal Area
S4	Vukiwale Kurisese	Qererqere Settlement	Sigatoka (West bank)
S5	Semisi Gadolo	Qererqere Settlement	Sigatoka (West bank)
S6	Ramesh Kumar	Lokia Settlement	Sigatoka (East Bank)
S7	Jeewan Singh	Lokia Settlement	Sigatoka (East Bank)
S8	Malakai Naceva	Qererqere Settlement	Sigatoka (West bank)
S9	Dharmen Kumar	Barara Settlement	Sigatoka (West bank)
S10	Arun Lal	Koronivia Settlement	Koronivia
S11	Mosese	Biausevu	Cane Coastal Area
S12	Maresilo Nasorowale	Komave	Cane Coastal Area
S13	Joeli Kuribua	Nawamagi	Sigatoka (East Bank)
S14	SRS Field 1	Nacocolevu	Sigatoka (West bank)
S15	SRS Field 2	Nacocolevu	Sigatoka (West bank)

<u>Long-term field trial with legume rotation and SST/balanced fertilization</u>

A long-term trial to investigate the benefits of two different soil management practices, legume rotation and root zone fertilization using WorldVeg SST (the application of a small quantity of highly concentrated nutrient solution near the root zone after transplanting in order to reduce overall fertiliser use), on soil health improvement began at Sigatoka Research Station, Fiji in March 2015. A preliminary trial to determine appropriate nutrients and rates for tomatoes in Fiji was conducted at Sigatoka Research Station, in June 2014. The first phase of the trial was legume rotation. The 3 selected legumes (mucuna, cowpea and yard long bean) were planted in the field in April 2014 prior planting of tomato in the regular season with an application of the starter solution. The treatment effects were measured by examining the physical and chemical properties of the soil before planting the legumes and after harvesting the tomato.

Activity 3.4: <u>Research station field days and on-farm demonstrations to promote adoption of technologies.</u>

<u>Extensive promotion of adapted varieties to vegetable growers during field days</u>

i) Field days in Fiji: The fresh market and cherry tomato varieties selected for Fiji were officially released at field days held at Sigatoka Research Station and Veiuto School in Suva on 30 September 2015 and 14 October 2016 respectively. The events were co-organised by the ACIAR project team (MOA, SPC and WorldVeg) to promote adoption of the adapted varieties to farmers, the public and the private sector representatives.

ii) Field days in Solomon Islands: The three tomato lines (2 fresh market and 1 cherry) and the capsicum line selected for Solomon Islands were officially released at field days in Honiara on 25 February 2014, 8 December 2016, and 23 February 2017. The events were jointly organised by MAL and WorldVeg to promote the adoption of the adapted varieties by local farmers and growers.

<u>Dissemination of information on improved vegetable production technologies</u>

During the field days in both countries, background information and seeds of officially released varieties were disseminated to the local communities. Information on improved vegetable production technologies were also disseminated during training held for MOA staff and farmers in each country.

i) Training on tomato grafting in Solomon Islands

Previous field trials testing grafted tomato scions onto disease-resistant and flood-tolerant eggplant rootstock confirmed that grafting technology can extend tomato production into the rainy season in Solomon Islands. A one-day training workshop on tomato grafting was conducted at the TTM farm in Honiara, Solomon Islands on 27 November 2014. The objective was to introduce grafting technology to interested farmers, RTCs and NGO staff, RTC internship students, and MAL research officers for its adoption in the Solomon Islands. The training, which was attended by 30 people, was run by Pita Tikai and Ellen Imaru and it consisted of presentations, video clips on grafting, and hands-on practical exercises. Due to the high level of interest that the grafting workshop generated, two further grafting training workshops for farmers were conducted at Burns Creek and Henderson on 2nd and 15th of March 2017, respectively. A total of 38 farmers attended the two workshops where they were trained in grafting techniques and how to build a “healing chamber” using locally available building materials. At the end of the training, each farmer was given a seedling of the WorldVeg disease-resistant and flood-tolerant eggplant rootstock, in order to produce his/her own seeds and a 1m long grafting tube to continue to practice grafting.

ii) Vegetable and tomato production training workshops in Solomon Islands and Fiji

A three-day vegetable production training workshop for students and farmers was jointly organized by the TTM and the SPC Youth at Work Program in the Solomon Islands at the TTM farm from 7 to 9 March 2016. WorldVeg attended on 9 March to facilitate the training component on tomato production, while the training on commonly grown vegetables was conducted by TTM staff. The aim of the training was to increase the knowledge and skills of participants in raising healthy seedlings, nursery management (soil media preparation, seed sowing, and pricking), field preparation and management practices (transplanting, staking, weeding & pruning), and pest and disease management.

Training for farmers on tomato production and marketing was organized by SPC, WorldVeg and the MOA, at Sigatoka Research Station on 31 May 2016. The objectives of the training were to refresh and educate farmers on how to produce, store, and sell fresh tomatoes, support the PGS project, improve farmer knowledge on “growing tomato for business”, and promote collaboration between all stakeholders (including Shangri-La Resort and Spa and the PGS project) involved in the local tomato supply chain. The topics covered included growing tomatoes in a business farming system, and tomato production, management and post-harvest handling. Participants visited the project’s tomato demonstration plots at Sigatoka Research Station to see the improved field management practices.

iii) Training of trainers (ToT) on vegetable GAP and seed/seedling production in Fiji

A week-long ToT on GAP and seed/seedling production was conducted at the Sigatoka Research Station, Fiji, from 10 to 14 March 2014. It was attended by a total of 34 farmers, nursery/potential nursery owners, and agriculture officers. The training consisted of lectures, participatory learning, and group presentations, followed by practical sessions. At the end of every session, the participants were given the opportunity to share their own experiences with other participants. The workshop was facilitated by Greg Luther (WorldVeg), Willie Chen (WorldVeg), Ellen Iramu (WorldVeg) and Aloesi Hickes (SPC).

6 Achievements against activities and outputs/milestones

Objective 1: To develop co-ordination and information-support systems for intensified horticulture

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Establish and sustain Program Advisory Group	Project Advisory Group (PAG) established and sustained	PAG established February 2012	The project planned 5 annual PAG meetings. Due to the close relationship established with the FAO-TCP on IPM promotion and pesticide reduction and HORT/2010/065, we were able to hold 4 additional PAGs throughout the lifetime of the project. The PAG was established at the project inception workshop, SRS, Fiji February 2012. A second PAG meeting was convened at SRS (in conjunction with the FAO-TCP) 30 July-3 August 2012 and a third PAG convened at Vaini research station, Tonga 13-15 February 2013. The fourth PAG (in conjunction with the FAO-TCP) convened at Vaini research station 17-19 September 2013 and the fifth PAG convened at Nu'u research station Samoa 18-20 February 2014. The sixth PAG (again, held in conjunction with the FAO-TCP and in conjunction with project HORT/2010/065) was held in Suva, Fiji late November 2014.The seventh PAG, hosted by NARI as part of HORT/2010/065, convened in Lae, PNG in April 20-24, 2015. The eighth PAG was hosted by MAL, Solomon Islands 20-25 July 2015. The ninth and final PAG was held at SRS, Fiji 20-24 July 2016, this also served as the forum for the end of project review.
1.2	Plant Health Clinics tested in Solomon Islands	Introductory workshop and initial training workshop (Field diagnosis and how to run a plant clinic)	May 2012	The introductory workshop and training modules were run at SWIM Honiara, Solomon Islands May 21-24, 2012
		Establish and run plant clinics	December 2017	Since completion of the formal pilot study, project staff in Solomon Islands have held further clinics. In 2014 funding from UNDP SWOCK underpinned clinics held on Isabel (3 clinics) and Makira (2 clinics). In 2015 a further 2 clinics were held in Solomon Islands. At the 7th PAG meeting (Honiara, July 2015) other project countries reiterated their desire to run a clinics program. In line with 2015 planning, PHC activities were conducted in Samoa (training on Upolu [19 MAF staff] 28-30 September 2015, clinics run at Agricultural show 12-16 October, training on Savai'i [14 MAF staff] 4-7 April 2016). In Fiji a PHC training program [6 MAFF extension staff] was conducted, clinics attracted 57 farmers. Details of additional PHC training and activities and clinics run are shown in **Tables 7.1 and 7.2**.
		Basic plant healthcare and advice-giving workshop	March 2013	5-day training of plant health "doctors" from MAL, KGA and VBMS held at KGA, Burns Creek February 25- March 1, 2013
		Plant clinic evaluation	September 2013	Dr Jeff Bentley independently evaluated the pilot Plant Health Clinic program in Solomon Islands in September 2013 and provided a detailed set of recommendations that were acted upon.

1.3	Establish advisory committee to edit Solomon Island Pest Fact Sheets and the book Diseases of Cultivated Crops in Pacific Island countries to make relevant for region; make available on line and in hard copy	Advisory committee formed	December 2017	The advisory committee was formed at the project inception workshop in 2012 and agreement to edit exiting facts sheets and contribute to the writing of new ones was reached. Members of the committee again confirmed their commitment to help edit fact sheets at the 8th PAG in Honiara, Solomon Islands in July 2015. However, Grahame Jackson has done this work single-handed.
		Pest Fact sheets edited, printed and available online	December 2017	10 bound copies of the Farmer factsheets (90 factsheets) and 10 copies of the Extension factsheets (90 factsheets) were printed for the PHC training workshop in Solomon Islands (May 2012). These, and an additional 350 fact sheets developed during the project are available online at adder.cbit.uq.edu.au - /project_files/Solomon Islands/Fact sheets/ The PAG decided that a better approach would be to produce app containing all these factsheets (plus additional resources). The "Pacific Pests and Pathogens" app was developed and published for free download (Google store and iTunes) in 2014. Version 2 was published in May 2015. Since then, iteratively improved versions have been published. The latest, Version 6, contains 350 Fact sheets and was published in November 2017. Under HORT/2016/185 Version 7 (containing 400 fact sheets) will be published in early 2019. Savings in publication costs from elsewhere (see immediately below), allowed purchase of 9 Samsung Galaxy Tablets (2 for each collaborating national ministry, 1 for SPC).
		Diseases of Cultivated Crops in Pacific Island book edited and printed	Did not proceed	Committee decided (February 2012) not to update the book "Diseases of Cultivated Crops in Pacific Island countries" and to allocate saved funds to printing/ dissemination costs elsewhere; 9 Samsung Galaxy Tablets were purchased and distributed to project members to use and help development of the "Pacific Pests and Pathogens" app.
1.4	Complete IPM training manuals (extension officer and farmer versions) developed in previous ACIAR initiatives; make available on line and in hard copy.	Advisory committee formed IPM manuals collated, updated and printed and available online	December 2017	Materials received from each country are available online (adder.cbit.uq.edu.au - /project_files/). During the project, IPM extension material development focused on the further development of pest and disease fact sheets for the "Pacific Pests and Pathogens" app- each fact sheet contains IPM advice for each pest and disease that it covers. Electronic copies of the manuals were shared with Sandra McDougal for use in ACIAR funded ICM work in The Philippines.
1.5	Conduct independent evaluation of Pestnet, update website and provide basic infrastructure for improved diagnostic advice in the region	Pestnet service independently evaluated Website updated	September 2013	Professor Geoff Norton (QBIT) conducted an independent evaluation of Pestnet. The report was delivered in March 2014 and presented at the next PAG. The Pestnet website was updated in line with the recommendations of the independent evaluation. The suggestion to develop a second app to facilitate data recording when taking images for posting on Pestnet has been taken up. This app will be developed under the new project HORT/2016/185, work on the app will begin in 2018.

Objective 2: To diagnose emerging pest and disease problems and develop management tactics

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Insecticide resistance status of DBM determined in Fiji, Samoa, Tonga and Solomon Island. Insecticide resistance management strategy designed and implemented in Fiji.	Susceptibility of field populations of DBM to major insecticides quantified.	December 2017	**Fiji:** In late 2012/ early 2013 DBM populations collected from farms in the Sigatoka Valley demonstrated high levels of resistance to Suncis (deltamethrin) (RR= 12-30), Steward (indoxacarb) (RR= 1.5-26), Match (lufenuron) (RR=3-18) and Prevathon (chlorotraniliprole) (RR=1.9-12.9) but all were very susceptible to Bt. Studies in 2013 focused on DBM collected from 2 sites on Vanua Levu, Fiji. DBM resistance to insecticides varied between sites; significant resistance to Steward (RR=77) and Suncis (RR=18) was recorded at one site but not at the other; there was evidence for increased tolerance to Prevathon at both sites (RR= 3.5 and 5.9). In 2014 (June-September) further resistance monitoring of DBM populations showed that there was decreased susceptibility to Match (RR= 4-13) but that resistance to Steward (RR=12), Suncis (RR=0.15- 2.1) and Prevathon (RR=0.7- 1.1) had declined markedly. Although no resistance was detected, evidence for decreased susceptibility to Bt (RR=6-12) was detected. By 2016, none of the DBM populations studied in Vanua Levu demonstrated any evidence of resistance to any of the insecticides studied (RRs: Bt= 0.5; Match= 1.0; Prevathon= 1.6; Steward= 1.3). In 2014 populations from the lower (SLV) and mid (SMV) regions of the Sigatoka valley, Viti Levu showed evidence for slightly increased tolerance to Match in the SLV population (RR=8) but susceptibility to all other insecticides (Bt, Prevathon, Steward, Suncis and Multiguard (abamectin) was high. In 2015 further monitoring in the lower Sigatoka valley Viti Levu showed that there was no evidence for DBM resistance to key selective insecticides (RRs: Bt= 1.4-4.3; Match= 2.8-3.4; Multiguard 1.9-3.7; Prevathon 2.6-2.8; Steward 0.8- 1.8) and similar data were collected in 2016 (RRs; Bt= 0.23; Match= 5.4; Multiguard= 1.5; Prevathon= 0.7; Steward= 1.7) and for *most* insecticides in 2017 (Bt= 2.2; Match= 1.3- 5.8; Prevathon= 0.6-0.7; Steward= 2- 3). Note, Multiguard showed resistance levels of RR=12- 27; this is cause for concern.
		Initial measures of insecticide resistance in populations in Samoa, Tonga and Solomon Islands	December 2015	**Samoa and Tonga:** In **Samoa** 3 field populations were established in 2013; in two of these there was evidence for increased tolerance to Match (RR= 4.5-4.7) but all populations were susceptible to all other insecticides tested (RRs: Attack (Pirimiphos-methyl/permethrin) = 0.8-2.5; Prevathon= 1.0-2.4; Bt= 0.3-1.7). Further testing of field populations in 2015 showed that populations remained susceptible to all insecticides tested, but there was evidence of a decrease in susceptibility to Bt in some populations RRs: Attack= 0.3-1.1; Prevathon= 0.6-2.4; Match= 0.2-1.4; Bt= 1.2-8). In **Tonga** a single field collected population established in late 2013 was highly resistant to Suncis (deltamethrin) (RR=68) but susceptible to all other insecticides tested. In 2014 four field populations demonstrated very high levels of resistance to Decis (deltamethrin) (RRs 70-976) but there was no resistance to Bt or any other insecticides introduced. Field collections in 2015 were not tested for deltamethrin resistance but there was no evidence of resistance to Bt or any other insecticides. **Solomon Islands:** Logistically, it was not possible to conduct insecticide resistance tests in Solomon Islands during the project.

		IRM strategy implemented in Fiji.	July 2014-	An IRM strategy devised and implemented in Fiji (June/ July 2014); workshops introducing strategy also held in Samoa and Tonga. Bt is integral to the strategy but was previously not available in Fiji, Tonga, Samoa or Solomon Islands. In collaboration with AgChem (Fiji), Bt was imported into Fiji from China. It is marketed as "AgChem Bt" and sold with a sticker in 500g packets; the IRM strategy is part of the technical information on the product label. The product is now registered and available from retailers in Fiji and Tonga. **AgChem Bt sales in Fiji:** January 2014- June 2015, 500 kg (FJ$28,000); July 2015- June 2016, 150kg; sales figures for July- December 2016 unavailable; January -December 2017, 160kg; January- July 2018, 140kg. **AgChem Bt sales in Tonga:** January 2014- June 2015, 160kg (FJ$6000); July 2015- June 2016, 110kg; July 2016- June 2018, 60 kg. In the period, 2014-2015, after the IRM strategy was implemented, AgChem Fiji reported increased sales of selective insecticides recommended in the IRM strategy (Steward 472% and Prevathon 62% increases) but declining sales of broad-spectrum insecticides historically used for Brassica pest management (Suncis -20%, Bifenthrin -25% and Orthene -49% declines). More recent sales figures for these products are not available.
2.2	Evaluation of *Trichogramma chilonis* as a biological control agent for the large cabbage moth	Basic biology of interaction between *T. chilonis* and large cabbage moth understood	December 2017	Studies on host range and basic biology of *T. chilonis*-LCM interaction have been completed. Genetic research indicates that the *T. chilonis* established in Samoa are very similar to *T. chilonis* in Hawaii. Interestingly genetic analysis of LCM from Samoa and Fiji indicates that they are very similar to, but distinct from, LCM in Australia
		Host range status of Samoan population of *T. chilonis* determined	December 2017	The wide host range of this *T. chilonis* population has been confirmed; interestingly this appears to be central to its success as a natural enemy of LCM in Samoa. *T. chilonis* is routinely recovered from eggs of the endemic moth *Nyctemera baulus alba* that are laid on the common weed *Crassocephalum crepidioides* within and at the margins of cabbage fields. In Samoa the long- term field experiments investigating the relationships between the weed and crop host plants and *N. baulus alba*-*T. chilonis*-LCM indicate that a single population of *T. chilonis* parasitises both these (and other) hosts throughout Upolu and Savai'i. There is also a close relationship between the numbers of *T. chilonis* recruited to LCM eggs masses following recruitment to *N. baulus alba* eggs. Three species of *Trichogramma* (*T. chilonis*, *T. achaeae* and *T. australicum*) parasitise LCM and *Nyctemera baulus alba* eggs in Samoa but 98.5% of *C. pavonana* and 87.5% of *N. baulus alba* parasitism events can be attributed to *T. chilonis*.
		Suitability of *T. chilonis* for integration into biological control programs elsewhere in the Pacific understood	December 2017	Previously extensive surveys in Tonga and Fiji, where LCM is very common, failed to recover *T. chilonis* from LCM egg masses. Similarly, more limited surveys in Solomon Islands also failed to recover any *T. chilonis* parasitising eggs of LCM. In late 2015 a parasitised LCM egg mass collected in Fiji was parasitised by *T. achaeae*- such events appear to be very rare. Our genetic investigations and field studies indicate that interactions between *T. chilonis*, its non-pest host and their host plants might underpin the success of *T. chilonis* as a natural enemy of LCM in Samoa. Better understanding of these interactions will help assessment of the possibility of integrating the parasitoid into IPM programs elsewhere.
		Mass rearing and release protocols for *T. chilonis* established	December 2017	*T. chilonis* can be routinely reared in large numbers through several hosts in the lab in Samoa but work on mass release protocols <u>was not undertaken</u>. Rather, efforts have focused on the *C. crepidioides*-*N. baulus alba*-*T. chilonis*-LCM interaction in order to understand if it can be manipulated for improved biological control for LCM in the field.

2.3	Cultural control methods for the management of *Nisotra basselae* in Solomon Islands developed and tested	Effectiveness of different cultural control methods established Integrated strategy based on cultural controls developed and implemented in Solomon Islands	June 2015 Not completed	Scientists at MAL, SPC and UQ designed several field experiments to test different cultural controls for the management of *Nisotra basselae*. The studies were beset by ongoing problems. The final experiment (completed June 2015) did not collect soil samples (to analyse egg densities); adult densities were low and no differences in foliar feeding beetle numbers were detected between treatments. Given the ongoing difficulties that is work suffered it was decided in 2015 that no further resources should be allocated to it. Consequently, no integrated strategy was implemented in Solomon Islands.
2.4a	Evaluation of elicitors insect resistance in Brassica crops	Effectiveness of elicitors of plant resistance responses to herbivory for manipulating insect distributions and attracting natural enemies determined.	December 2017	Laboratory work has shown that head cabbage and Chinese cabbage plants display detectable responses to herbivory and that in common cabbage these can be manipulated to alter DBM oviposition patterns for up to 6 days after plants were damaged. A field study in Samoa showed that exogenous application of jasmonic acid to plants in the field could concentrate DBM eggs on those plants- thereby effectively turning the treated portion of the crop into a "trap-crop". Laboratory studies have shown that herbivore damaged and jasmonic acid (JA) treated cabbage plants are attractive to parasitic wasps but that associative learning is extremely important in determining the responses of parasitoids to plant volatiles and that this must be considered when these strategies are implemented for improved pest management in the field.
2.4b	Evaluate biochemical elicitors of pathogen resistance in Solanaceous crops	Efficacy of phosphoric acid salt (PAS) to enhance resistance to tomato (bacterial spot, grey leaf spot) foliar pepper (bacterial spot and cercospora leaf spot) and soil-borne (bacterial wilt) diseases determined	2014 Partial completion – November 2016	The greenhouse experiments to evaluate 5 plant activators confirmed that phosphorous acid salt, BION™, and ReZist™ have a broad-spectrum control effects on tomato and pepper diseases. Anti-Rot®, a commercial Phosacid systemic fungicide, available in Fiji and Solomon Island was evaluated in a replicated field trial in Solomon Islands in 2016. Preliminary observations showed that the foliar disease incidence on tomato was reduced to about 15% severity.
2.5	Develop improved techniques for disease diagnosis and monitoring in targeted vegetable crops	Molecular diagnosis of *Colletotrichum* species causing pepper anthracnose improved A procedure for molecular diagnosis of tomato foliar diseases	August 2014 February 2017	A paper-based molecular diagnosis protocol using FTA™ cards has been developed and used successfully with PCR based diagnostics and species-specific primers. The FTA™ card protocol was developed to support remote diagnosis of diseases and the causal pathogen(s). Samples sent on FTA™ cards were diagnosed to confirm *C. acutatum* as the predominant pathogen causing anthracnose on chilli pepper in Fiji and on sweet pepper in Solomon Islands. A procedure for molecular diagnosis of tomato foliar diseases was develop and validated and used to identify samples collected during field surveys of tomato diseases in Fiji and Solomon Islands in November 2016. Predominant causal pathogens of tomato diseases in both countries have been identified using this diagnosis technique.
2.6	Assessment of susceptibility of four varieties of potato imported from NZ to bacterial wilt *Ralstonia solanacearum*.	Degree of susceptibility of imported varieties to endemic *R. solanacearum* determined	Ongoing	Soil samples collected from 36 sites in Fiji. Potatoes grown in two soil samples (both from Sigatoka valley) succumbed to *R. solanacearum*- the strain was not established.

Objective 3. To develop integrated approaches for intensifying vegetable production (Lead organization: WorldVeg with SPC)

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Use of standard screening procedures (developed in PC2005/077) to field evaluate improved varieties of Solanaceous crops for quality and market potential, as well as the prospects of extending production seasons in Fiji, the Solomon Islands, Samoa, and Tonga.	Variety evaluation procedure (including sites) revised to be suitable for each target country.	2013	Variety evaluation protocols for tomato, sweet pepper and chilli developed between 2012 and 2013 were utilised by project partners.
		Potential varieties selected based on a set of defined criteria and seeds acquired for trials	2014	Three field trials investigating 11 WorldVeg improved OP tomato lines (8 Fresh Market & 3 Cherry) and 10 sweet pepper lines were completed in Fiji over 3 regular cropping seasons from 2012 - 2014. Varieties were eliminated in each round using two selection criteria: field performance (yield and fruit quality) and organoleptic test (taste, appearance, firmness).
		Suitable adapted varieties of Solanaceous crops for regular season production identified.	2016	Variety evaluation trials for tomato and sweet pepper in Fiji (2015) and Solomon Islands completed (2016) were completed. Two tomato lines, 1 fresh market tomato (Melrose) & 1 cherry tomato (Rio Gold) with were officially released in 2015/16. Similarly, in Solomon Islands, three tomato lines - 2 fresh market tomato (locally known as Rose's Choice and MAL Fresh) and 1 cherry tomato (MAL Cherry) were officially released in 2014, 2016 and 2017. A sweet pepper variety (MAL Wonder) was also officially released in Solomon Islands in March 2017. For Fiji, a sweet pepper line is yet to be selected for official release despite the completion of field trials in 2016.
		Adapted varieties for extending the production season of each crop identified.	2015	Variety evaluation trials in Samoa were discontinued in 2014 after the confirmation trial stage. In Tonga, field trials were not continued after the observation stage. An off-season tomato variety trial was completed in Fiji in May 2016. Two new hybrid varieties (Sensation & King Kong #2) of Known You origin were shown to perform well during the rainy season when compared to the local check variety (Raising Sun #2) which is a commonly grown hybrid variety. The varieties were investigated for resistance to bacterial wilt-although the variety Grace performed well in the field, but it was not selected because it was susceptible to bacterial wilt.
			2014	Three WorldVeg flooding-tolerant eggplant rootstocks were evaluated for grafting tomato in Solomon Islands; they were promoted after the successful tests. Field trials during the 2014 wet season showed that grafted plants could better withstand water-logging conditions and produce better marketable yields when compared to non-grafted plants.

No.	Activity	Outputs/ milestones	Completion date	Comments
3.2	Evaluation ICM practices for improved pest and disease management in year-round vegetable production in Fiji, the Solomon Islands, and Samoa	Understanding current practices and constraints on crop management, postharvest and marketing.	October 2012	Surveys that were designed to better understand current practices and constraints to crop management, post-harvest handling and marketing of tomatoes were conducted in target locations in September and October 2012. The survey report was completed and published as joint publication between SPC and MOA in 2013.
		Seedling production technology developed in PC/2005/077 adapted and improved.	2015	A range of different potting media for the plug tray system was evaluated. An improved medium consisting of equal parts soil, grated coconut husk and thrive (Yates) was identified and recommended to farmers Fiji. This medium has good water retention properties and promotes vigorous growth and healthy root development in tomato seedlings.
		Simple drip irrigation kits evaluated for effectiveness and durability (in dry areas).	Not completed	Drip irrigation kits were purchased and stored in the Sigatoka ICM Project office. However, irrigation trials were not conducted and so their effectiveness and durability were not evaluated.
		Suitability of protective structures for extending production season determined (in wet areas).	2016, thereafter continued by PARDI project	In collaboration with the PARDI project , trials at Sigatoka Research Station evaluated tomato, capsicum, cucumber and sweet pepper production in protected structures. valuated. Two offseason plantings were conducted between November 2015 and April 2016. Trials under the structure continued through 2017 under the PARDI project.
		Utility of insect exclusion nets as a component of Brassica IPM on small holdings verified.	August 2016	Two field trials were conducted, one in Fiji (2014) and one in Solomon Islands (2016). These showed that covering plots of cabbage with MikroKlima® GrowCover from transplanting to the post cupping stage, from pre-cupping to the post cupping stage and subsequent application of Bt resulted in higher marketable yields than in the control plots, which suffered high levels of pest damage.
		A range of pest and disease management tactics evaluated for specific circumstances.	Partial completion – December 2016	The severity of the major diseases of tomato in the regular season was recorded and the causal pathogens identified using the FTA™ card protocol. Application of PAS to control tomato foliar diseases was evaluated in Solomon Islands in 2016 and found to be effective. However, further field trials are required to confirm results before PAS can be recommended to framers for field control of tomato diseases.

No.	Activity	Outputs/ milestones	Completion date	Comments
3.3	Evaluate soil management practices (including use of biochar, legumes as rotation crops, and balanced fertilization) to promote sustainable soil health in Fiji.	Current status of soil health determined in pilot sites.	January 2013	A soil health survey was conducted (October 2012 to January 2013) and soil samples collected from 15 farms in the Sigatoka Valley, Cane Coastal area and Koronivia. Farm characteristics were recorded and measurements of 11 soil health indicators were conducted.
		Suitable legume crops evaluated and identified as rotation crops.	March 2014	Mucuna bean, cowpea and yard long bean were identified and selected as suitable legume crops for evaluation based on their field performance, and their potential (in the case of cowpea and yard long bean) for income generation.
		Long term field trials with legume rotation and SST/ balanced fertilization conducted.	Partial completion	The legume rotation phase was completed in October 2015 and soil samples collected for lab analyses. At the end of the project, trial plots were left fallow. The planned tomato rotation, application of SST and balanced fertilisation were not completed, but optimum SST concentration for Fiji was determined and tested in the field.
3.4	Research station field days and on-farm demonstrations to promote adoption of technologies.	Farmers experience new technologies through participatory trials.	March 2017	Field-days were held at Sigatoka Research Station (30 September 2015) and Veiuto school, Suva (14 October 2016) in Fiji. The events were organised for farmers, and public/ private sector representatives to witness the official release of the selected fresh market and cherry tomato lines now locally known as Melrose and Rio Gold, respectively. During the events, information on tomato production and gross margin was provided and seeds of the released varieties were distributed to participants. Fruits of the varieties were also displayed for public viewing.
		Information on improved vegetable production technologies disseminated.		In Solomon Islands, three field days were organised in Honiara (25 February 2014, 8 December 2016 and 23 February 2017). As in Fiji, these events were organised to officially release and promote three tomato lines (2 fresh market (Rose's Choice and MAL Fresh) and 1 cherry tomato (MAL Cherry)) and a sweet pepper line (MAL Wonder) to farmers and the public. Seeds and seedlings of the released varieties were distributed. Training for local agriculture stakeholders and farmers was conducted in Fiji and Solomon Islands from 2014 – 2017. In Fiji, training on GAP and seed/ seedling production, and tomato production and marketing was conducted in 2014 and 2016 respectively. In Solomon Islands, training on grafting to promote the technology for adoption by local growers and farmers was conducted in 2014 and 2017. Farmers were also trained in vegetable/ tomato production.

7 Key results and discussion

Objective 1: To develop co-ordination and information-support systems for intensified horticulture

Activity 1.1: Establish and sustain Program Advisory Group

The project advisory group (PAG) was established in 2012 and functioned reliably throughout the project. Clear demonstrations of its success are that it integrated very effectively with the FAO-TCP and that it forms the framework to the new ACIAR project "Responding to emerging pest and disease threats to horticulture in the Pacific islands" (HORT/2016/185).

Activity 1.2: Plant Health Clinics tested in Solomon Islands

The independent review of the pilot PHC project in September 2013 praised the publicity that was given to the clinics and the collation of the data generated. The review also identified problems with the pilot study that could compromise their success, specifically confusion over the leadership of the clinic program and the timing and location of the clinics. In order to improve the program in Solomon Islands it was recommended that: i) leadership issues should be clarified, ii) clinics should be held regularly in "farmer friendly" placed (*i.e.* markets rather than villages), iii) clinics should be run by a small group of local plant doctors, iv) further plant doctor training is needed, v) clinics should send more samples for identification, vi) recommendations made at the clinics should be more specific and only advocate technologies that are available to farmers in the area. The review made the following recommendations for any clinic program that is to be developed in other Pacific countries: i) the program should focus on *extension* staff and be written into their terms of reference, ii) leadership of the program must be clearly defined and a clinic "*champion*" identified to drive the initiative iii) clear training and pilot timetables need to be developed and the Solomon Island factsheets developed for local use, iv) the clinic program should be viewed as a component of a larger plant health system. These recommendations were all adopted as the concept of PHCs was developed and further tested throughout the project and they form the core of the regional PHC program that is a key objective of HORT/2016/185. Further project funded training and PHC activities that took place from 2015 are summarised in Tables 7.1 and 7.2

Table 7.1 PHC training activities run in Solomon Islands, Samoa and Fiji from 2015

Country	PHC Activity	When	Where	No. attending	Trainers*
Samoa	Training MAFF extension staff	28-30 September, 2015	Upolu	19	GVHJ; MJF
Samoa	Training MAFF extension staff	4-7 April 2016	Savaii	14	GVHJ
Solomon Is	1st training for extension staff	6-10 March 2017	Honiara	12 (7 provinces)	GVHJ
Solomon Is	Guadalcanal staff revision	1-3 July 2017	Honiara (Extension HQ)	10 (Guadalcanal)	PT
Fiji	Revision & updates	27 June 2017	Sigatoka Research Station	14: 8 Extension; 4 Research, 2 Interns	MM

*GVHJ= Grahame Jackson; MJF= Mike Furlong; PT= Pita Tikai; MM=Mani Mua.

Table 7.2 Additional PHCs run in Solomon Islands, Samoa and Fiji from 2015

Country	Activity	When	Where	No. attending	Major issues
Solomon Is	PHC	9 March 2017	Central market	44 (18f; 26m) 5 samples	Watermelon GSB, bele borer, cabbage caterpillars, Papuana, GAS, capsicum whitefly, anthracnose capsicum
Solomon Is	PHC	22 June 2017	Central Market	34 (14f; 20m) 1 sample	Papuana, DBM, watermelon GSB, GAS, bele borer, cabbage caterpillars
Solomon Is	PHC	4 July 2017	Vutu, Guadalcanal (north east)	35 (23f; 12m) 47 samples	Papuana, taro armyworm, banana scab moth, citrus scab, sweet potato leaf folder, GAS, guava fruit fly, cabbage caterpillars, capsicum whitefly, cocoa black pod, bele borer, BER tomato
Solomon Is	PHC	17 October 2017	Honiara Ag Show (World Food Day)	6 (2f; 4m)	Eggplant spot, tomato thrips. cabbage caterpillars, GAS, tomato sunscald
Samoa	PHC	12-16 October	Agricultural show (Upolu)	20	Caterpillars and downy mildew on cucumber; black leaf mould and bacterial wilt on tomatoes and capsicum; LCM on cabbages, and BBTV on bananas.
Samoa	PHC	2 February 2017	Savaii Salailua	13 (2f; 11m)	LCM, BBT, cucumber spots, rots taro, pumpkin, cocoa
Samoa	PHC	21 April 2017	Upolu, Ulutogia, Aleipata	19 (12f; 7m)	Tomato & capsicum mites, caterpillars on Chinese cabbage, rots of pumpkins & breadfruit, damping off Chinese cabbage, cocoa black pod
Samoa	PHC	2 November 2017	Savaii, Salelologa	11 (2f; 9m)	Bacterial wilt, capsicum & tomato mites, cabbage caterpillars, head rot cabbages, cocoa black pod
Fiji	PHC	June 3, 2016	Nadi	57	Coconut pests; insect pests of vegetables: thrips, whitefly, DBM, LCM and leaf miners; weeds. Tomato Blossom end rot, Eggplant blossom blight, Chilli anthracnose, Gummy stem blight on cucurbits, Powdery and downey mildew on okra.
Fiji	PHC	27 April 2017	SRS, Nacocolevu	14 (1f; 13m)	Eggplant thrips, bean leaf miner, sweet potato scab, tomato wilt, GSB, capsicum sunscald, whiteflies
Fiji	PHC	8-10 November, 2017	Ag Show Nadi	-	Anthracnose capsicum, coconut rhinoceros beetle, eggplant/tomato flea beetles, borer on beans and tomato, whiteflies on vegetables (and others: tomato bacterial wilt, Papuana, GSB, blight of tomato, mealybugs on vegetables)

The recent activities in PHC training and running of clinics (Tables 7.1 and 7.2) have often been driven by the national ministries in collaborating countries. They are well attended by farmers, clearly showing the enthusiasm with which the program has been met and the benefits that it provides to both extension officers and farmers in the region. Photo-sheet summaries of recent PHC activities are provided in Appendix 9.

Activity 1.3: Establish advisory committee to edit Solomon Island Pest Fact Sheets and the book Diseases of Cultivated Crops in Pacific Island countries to make relevant for region; make available on line and in hard copy.

The "Pacific Pests and Pathogens" app was published for free download (Google store and iTunes) in 2014. Version 2 was published in May 2015. Since then, iteratively improved versions have been published. The latest, Version 6, contains 350 Fact sheets and was published in November 2017. Under HORT/2016/185, Version 7 (containing 400 fact sheets) will be published in early 2019.

Activity 1.4: Complete IPM training manuals (extension officer and farmer versions) developed in previous ACIAR initiatives; make available on line and in hard copy.

10 bound copies of the Farmer factsheets (90 factsheets) and 10 copies of the Extension factsheets (90 factsheets) were printed for the initial PHC training workshop in Solomon Islands (May 2012). Electronic copies of the manuals were shared with Sandra McDougal for use in ICM work in The Philippines. The original fact sheets and those developed during the project (a total of 350 fact sheets) are available online at adder.cbit.uq.edu.au-/project_files/Solomon Islands/Fact sheets/

Activity 1.5: Conduct independent evaluation of Pestnet, update website and provide basic infrastructure for improved diagnostic advice in the region.

The independent review of Pestnet made six recommendations: i) to seek funding to support new technology and future management strategies, ii) in the immediate future, maintain the focus of Pestnet on improving services to the Pacific Islands, SE Asia and Asia, iii) explore possibility of developing a smartphone app for improving the metadata included with requests for management, ID and diagnostic assistance iv) improve ways in which the Pestnet website can provide additional support to the email system, v) investigate how other plant protection sites and services could complement Pestnet activities and vi) develop a succession and future management plan.

The Pestnet website was updated in line with the recommendations of the independent evaluation. The suggestion to develop a second app to facilitate data recording when taking images for posting on Pestnet could not be taken up during the project but the app will be developed under the new project HORT/2016/185. Work on the app began in 2018.

Objective 2: To diagnose emerging pest and disease problems and develop management tactics

Activity 2.1: Insecticide resistance status of DBM determined in Fiji, Samoa, Tonga and Solomon Islands. Insecticide resistance management strategy designed and implemented in Fiji.

Regional status insecticide resistance in DBM.

A full summary of the responses of field populations of DBM from Fiji (2012-2017), Samoa (2013-2105) and Tonga (2013-2015) is shown in Appendix 10.

In 2013 populations of DBM collected from farms in the Sigatoka Valley, Fiji demonstrated high levels of resistance to Suncis (deltamethrin) (RR= 12-30), Steward (indoxacarb) (RR= 1.5-26), Match (lufenuron) (RR=3-18) and Prevathon (chlorotraniliprole) (RR=1.9-12.9) but all were very susceptible to Bt (Appendix 10). Similarly, high levels of resistance were exhibited by some populations on Vanua Levu in 2103. In 2014, the IRM strategy was introduced and DBM populations were collected from the crops of cooperating farmers through to 2017. In general, the resistance levels were significantly reduced and the susceptibility of the field populations to Bt and Multiguard (abamectin), the other selective insecticide introduced by the project, has been maintained (Appendix 10). Data from the Sigatoka Valley illustrates the impact that the IRM strategy that was implemented in 2014 has had on the local status of insecticide resistance in DBM (Figure 7.1). Following implementation of the strategy in 2014, Suncis was no longer used on cooperating farms and susceptibility to it was not monitored, however, resistance to Steward and Prevathon, both of which are integral to the IRM strategy, declined and the susceptibility of DBM to these and the other insecticides monitored remained high through to the end of 2017.

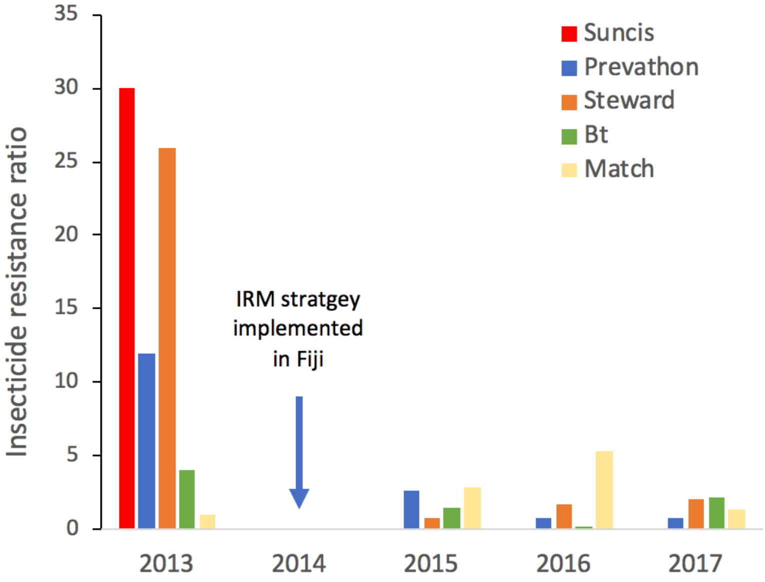

Figure 7.1. Susceptibility of DBM populations collected from the lower valley, Sigatoka, Viti Levu Fiji to a range of insecticide before and after the introduction of the IRM strategy in 2014.

In Samoa 3 field populations were established in 2013; in two of these there was evidence for increased tolerance to Match (RR= 4.5-4.7) but all populations were susceptible to all other insecticides tested (RRs: Attack (Pirimiphos-methyl/ permethrin) = 0.8-2.5; Prevathon= 1.0-2.4; Bt= 0.3-1.7). Further testing of field populations in 2015 showed that populations remained susceptible to all insecticides tested, but there was evidence of a decrease in susceptibility to Bt in some populations (RRs: Attack= 0.3-1.1; Prevathon= 0.6-2.4; Match= 0.2-1.4; Bt= 1.2-8) (Appendix 10). In Tonga a single field collected population established in late 2013 was highly resistant to Suncis (deltamethrin) (RR=68) but susceptible to all other insecticides tested. In 2014 four field populations demonstrated very high levels of resistance to Decis (deltamethrin) (RRs 70-976) but there was no resistance to Bt or any other insecticides introduced. Field collections in 2015 were not tested for deltamethrin resistance but there was no evidence of resistance to Bt or any other insecticides (Appendix 10).

Design and implementation of Insecticide Resistance Management (IRM) strategy in Fiji.

The implemented IRM strategy is summarised in Figure 7.2. The strategy is founded on the regular rotation of selective insecticides with different modes of action (MoA) based on an 18-day temporal window. It was introduced to farmers at “Pesticide Forums” in Vanua Levu and Viti Levu in 2014; the recommended window sequence in which insecticides should be used is as follows:

i) *1st window:* Multiguard (abamectin; MoA Group #6): first window, selective insecticide with translaminar properties (this allows it to target leaf mining neonate DBM larvae)
ii) *2nd window:* AgChem Bt (Bt: MoA Group #11): minimal impact on natural enemies; at this stage the crop is most susceptible to foliar damage, >1 application allowed in the window.
iii) *3rd window:* Steward (indoxacarb: MoA Group #22) or Prevathon (chlorotraniliprole; MoA Group #28). Both insecticides are expensive and less selective than Multiguard and AgChem Bt, but many farmers use them. The strategy recognised this and recommended one or the other.
iv) *4th window:* Match (lufenuron; MOA Group #15) or Multiguard. Match is widely used and available. Could be used if already purchased, otherwise revert Multiguard which would not have been used for >2 DBM generations.

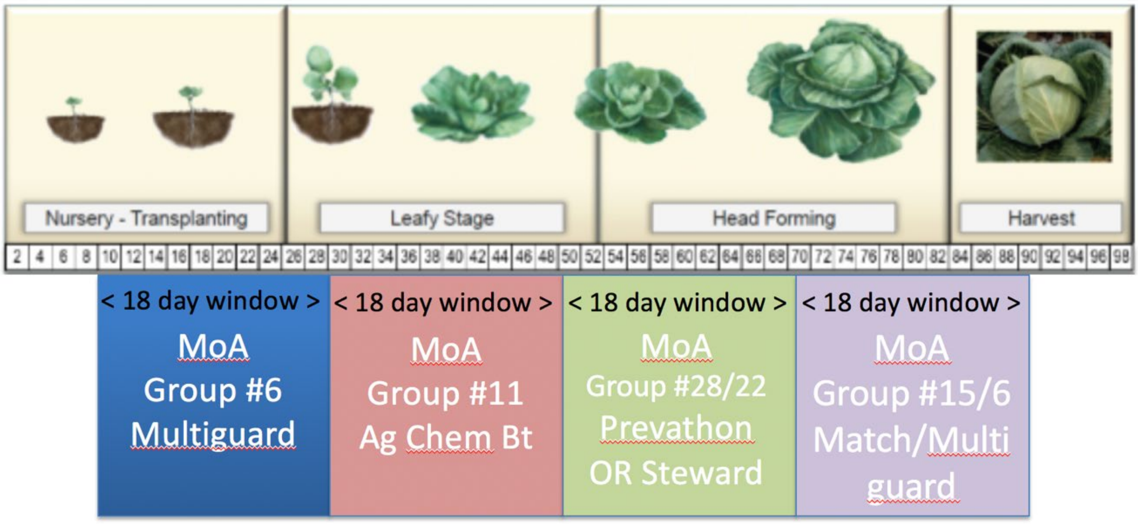

Figure 7.2. Summary of IRM strategy implemented for DBM in Fiji from 2014. The top panel shows the typical 3-month growing cycle for head cabbage. Insecticides with different modes of action (MoA) are rotated through 18-day "windows" to minimise the possibility that individuals in successive generations are exposed to the same insecticide, thereby reducing the selection pressure for resistance. The lower panel shows the recommend sequence of rotation of selective insecticides, MOA Group # represents the mode of action group that the insecticide belongs to (www.irac-online.org) Group #6 = glutamate-gated chloride channel allosteric modulators; Group #11 = microbial disruptors of insect midgut membranes; Group #15 = inhibitors of chitin biosynthesis, type 1; Group #22= voltage dependent sodium channel blockers; Group #28 = ryanodine receptor modulators.

The AgChem Bt was promoted at the "Pesticide Forums" and particular attention (including site demonstration) was paid to its proper use and application. A small brochure (see Appendix 11) that was included with every sale of the product was also developed. This included details on how the product should be used and a summary and explanation of the IRM strategy. The AgChem Bt packaging also contained information on the IRM strategy (Appendix 11). The strategy was not uniformly adopted, but farmers exposed to it embraced it and saw the benefits (see Figure 7.1). The change in practice that the strategy has achieved is evidenced by the change in insecticide use by farmers in the Sigatoka Valley since 2009 (Figure 7.3). Surveys conducted in 2009 (n=21 farmers), 2011 (n=21), 2015 (n=16) and 2107 (n-21) collected information on the number of farmers using a given insecticide against DBM in Brassica crops (Figure 7.3).

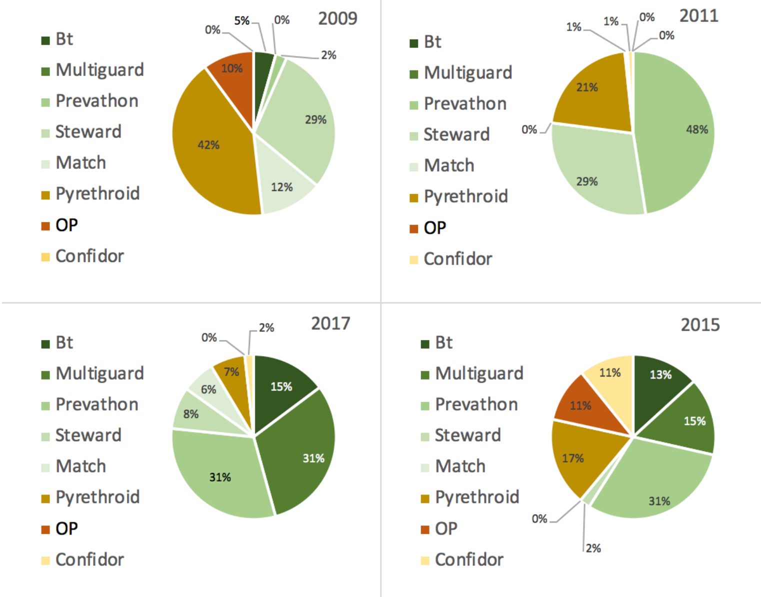

Figure 7.3: relative use of different insecticides against insect pests in Brassica crops in the Sigatoka Valley, Fiji 2009-2017.

There is a clear change over time (Figure 7.3). In 2009, pyrethroid and organophosphate compounds dominated the insecticides used but their use has gradually declined. Since 2015, Bt has been used consistently and it and the other selective insecticides promoted through the IRM strategy now dominate the insecticides used in the Sigatoka Valley. In addition to their effectiveness, these selective insecticides allow natural enemy populations to build up in crops. These can be extremely important mortality factors for DBM and they can be effectively incorporated into IPM strategies for the management of Brassica pests (Furlong et al 2008; Furlong et al 2013). Recent collections of DBM pupae for resistance testing have demonstrated the very high levels of parasitism by *Oomyzus sokolowskii* that can occur if broad spectrum insecticides are avoided and replaced by the judicious use of selective insecticides (Figure 7.4).

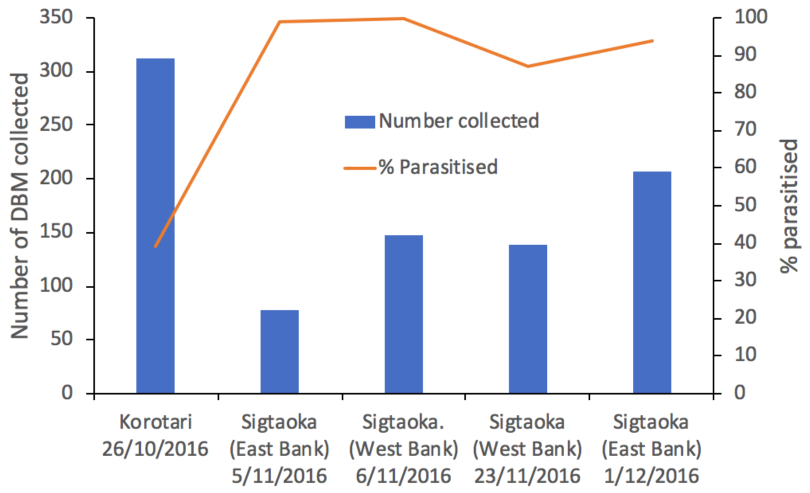

Figure 7.4: *Oomyzus sokolowskii* parasitism rates of DBM pupae collected at Korotari (Vanua Levu) and at several sites in the Sigatoka Valley (Viti Levu) in late 2016.

Laboratory validation of the IRM strategy.

In the laboratory, the resistance ratio (RR) of the deltamethrin resistant Q-delta population to deltamethrin declined from 11 to just 4 when reared in the absence of the insecticide for 4 generations (Table 7.3); however, when the same starting population was repeatedly selected with deltamethrin, its RR increased to 15 (Table 7.3). This suggests that deltamethrin resistance has a fitness cost for DBM, but clearly shows that resistance increases when the insect is repeatedly exposed to the insecticide. When the deltamethrin resistant Q-delta population was subject to the IRM strategy for 4 generations (exposed to a different insecticide each generation for 4 generations- see Figure 7.2) the RR to deltamethrin declined markedly to 5.5, but susceptibility to the insecticides used (abamectin, Bt and indoxacarb) did not change (Table 7.3). When the deltamethrin resistant Q-delta population was subject to repeated selection with Bt for 4 generations, again the susceptibility to deltamethrin declined, and while susceptibility to abamectin and indoxacarb did not change, susceptibility to Bt declined and the RR increased from 3 to 8. This demonstrates the problems associated with single tactic insecticide use against the pest and shows that, if consistently exposed to Bt (or any other insecticide) that DBM can rapidly develop resistance. Throughout the 4-month experiment the susceptibility of the Waite population to all test insecticides remained very stable, providing support for the argument that the changes in the susceptibilities to insecticides measured in the resistant populations were due to the different insecticide regimes tested and not due to rearing or other environmental conditions.

Table 7.3: Laboratory validation of the IRM strategy. A deltamethrin resistant population (Q-delta) was reared in the absence of the insecticide, repeatedly selected with deltamethrin (to replicate repeated exposure in the field), exposed to the IRM strategy or repeated selected with Bt.

Strain	Insecticide	Generation	LC_{50} [ppm] (95% CI)	RR[4]
Q-delta (Deltamethrin resistant strain)	Deltamethrin	G_1	123 (87.2-174.3)	11
	Abamectin	G_1	0.03 (0.02-0.04)	6
	Indoxacarb	G_2	1.2 (0.09-0.18)	2
	Bt	G_2	0.003 g/L (0.001-0.004)	3
Reared without exposure to insecticide for 5 generations	Deltamethrin	G_5	46.33 (32.9-64.4)	4.2
	Abamectin	G_5	0.009 (0.006-0.01)	1.8
	Indoxacarb	G_5	0.61 (0.4-0.9)	1.3
	Bt	G_5	0.0038 (0.002-0.006)	2.2
Q-delta-delta[1]	Deltamethrin	G_5	156 (107-228)	15
	Abamectin	G_5	0.008 (0.004-0.01)	1.6
	Indoxacarb	G_5	0.9 (0.6-1.2)	2.3
	Bt	G_5	0.003 (0.002-0.006)	3.0
Q-delta-IRM[2]	Deltamethrin	G_5	59 (40-86)	5.5
	Abamectin	G_5	0.01 (0.006-0.01)	2
	Indoxacarb	G_5	0.7 (0.4-0.9)	1.4
	Bt	G_5	0.003 (0.002-0.005)	3.0
Q-delta-Bt[3]	Deltamethrin	G_5	73.9 (48-110)	7
	Abamectin	G_5	0.009 (0.005-0.012)	1.8
	Indoxacarb	G_5	0.71 (0.4-1)	1.5
	Bt	G_5	0.008 (0.005-0.012)	8
Waite	Deltamethrin	G_1	10.68 (4.12-420.99)	
	Abamectin	G_1	0.005 (0.004-0.007)	
	Indoxacarb	G_1	0.6 (0.04-0.09)	
	Bt	G_1	0.001 g/L (0.0003-0.0008)	
	Deltamethrin	G_4	11.05 (3.9-95.6)	
	Abamectin	G_4	0.0053 (0.003-0.007)	
	Indoxacarb	G_4	0.46 (0.31-0.68)	
	Bt	G_4	0.0017 (0.0006-0.003)	

[1]Deltamethrin selected, G_1-G_4. [2] subjected to the IRM strategy, G_1-G_4. [3]Bt selected, G_1-G_4. [4] RR (resistance ratio) = LC_{50} of given insecticide against a given DBM population/ LC_{50} of given insecticide against Waite DBM population.

Activity 2.2: Evaluation of *Trichogramma chilonis* as a biological control agent for the large cabbage moth.

Basic biology of interaction between *T. chilonis* and large cabbage moth (LCM) and host range status determined

When reared in LCM eggs, single *T. chilonis* adults emerged from single eggs, however, when reared in the larger eggs of DBM, angel moth, eggfly or monarch butterfly, multiple *T. chilonis* adults emerged from single eggs (Table 7.4). In LCM eggs the sex ratio was F:M 60:40, similar to that in other species. Adult parasitoids were of a similar size, irrespective of the host eggs in which they developed (Table 7.4).

Table 7.4: Basic bionomics of *Trichogramma chilonis* reared in different host eggs in the laboratory in Samoa.

Host egg	Mean No. *T. chilonis* egg^{-1}	Female: Male	Male size (±SE) (mm)
LCM (*C. pavonana*)	Typically 1	60:40	0.533 (±0.010)
DBM (*P. xylostella*)	Typically 2	45:55	0.490 (±0.033)
Angel moth (*N. baulus alba*)	5.7	60:40	0.531 (±0.044)
Eggfly (*H. bolina*)	9.9	55:45	0.525 (±0.015)
Monarch *D. plexippus*	5	70:30	-

An extensive literature review showed that *T. chilonis* has been recorded from more than 130 species of Lepidoptera from 24 families (Uelese et al., 2014; Appendix 12).

Field studies showed that six species of egg parasitoids were recovered from LCM, Angel moth, Eggfly and fruit piercing moth (*Eudocima phalonia*) in the field (Tables 7.5 and 7.6).

Table 7.5: Egg parasitism of selected Lepidoptera in Samoa. Rates = % of egg masses (*C. pavonana*), egg clusters (*N. baulus alba* and *H. bolina*) and single eggs (*E. phalonia*) attacked. *Trichogramma* species identified by molecular methods, *Telenomus* and *Ooencyrtus* spp. identified by morphological characters. If sum % parasitism >100%, >1 parasitoid species was recovered from an egg mass, egg cluster or single egg.

Host species	Sample size (N)	Percent (%) parasitism of host species by:						
		Trichogramma chilonis	*Trichogramma achaeae*	*Trichogramma australicum*	*Ooencyrtus crassulus*	*Telenomus lucullus*	*Telenomus* sp. indet.	Unparasitised
Crocidolomia pavonana	207 egg masses	31.9	1.0	1.0	0.0	0.0	0.0	67.6
Nyctemera baulus alba	78 egg clusters	26.9	6.4	0.0	0.0	0.0	46.2	24.4
Hypolimnas bolina	65 egg clusters	67.6	6.2	6.2	18.5	0.0	0.0	4.6
Eudocima phalonia	191 single eggs	9.4	0.0	0.0	35.6	12.6	0.0	42.9

Table 7.6: Contribution to overall parasitism of selected Lepidoptera by three species of *Trichogramma* in Samoa. Rates = % of egg masses (*C. pavonana*), egg clusters (*N. baulus alba* and *H. bolina*) and single eggs (*E. phalonia*) attacked. *Trichogramma* species identified by molecular methods; when sum % parasitism >100, >1 parasitoid species was recovered from an egg mass, egg cluster or single egg.

Host species	Sample size (N)	Percent (%) of *Trichogramma* parasitism attributed to:		
		Trichogramma chilonis	*Trichogramma achaeae*	*Trichogramma australicum*
Crocidolomia pavonana	67 egg masses	98.5	3.0	3.0
Nyctemera baulus alba	24 egg clusters	87.5	20.8	0.0
Hypolimnas bolina	51 egg clusters	86.3	7.8	7.8
Eudocima phalonia	18 single eggs	100.0	0.0	0.0

Although LCM was attacked by three species of *Trichogramma*, >98% of parasitoids recovered from LCM eggs were *T. chilonis* (Table 7.6). There were no genetic differences between the *T. chilonis* recovered from LCM, *N. baulus alba* and *H. bolina.* This strongly suggests that a single interbreeding population of *T. chilonis* parasitises these different host in the field in Samoa.

<u>Suitability of *T. chilonis* for integration into biological control programs elsewhere in the Pacific understood and mass-rearing protocols for *T. chilonis* established.</u>

Field experiments in Fiji and Samoa showed that the “combined Bt intervention threshold” based on DBM density and proportion of the crop infested by LCM was effective (Figure 7.5) and that crops could be effectively managed using reduced inputs of the insecticide when compared with conventional practice. The use of Bt allows natural enemies to build in in crops, these then contribute to pest mortality reducing the need for further insecticidal interventions. Conventional insecticides (e.g. deltamethrin and Attack (pirimiphos-methyl/ permethrin) destroy natural enemies, leading to the build of pest numbers between applications (Figure 7.5). Natural enemy exclusion experiments (Figure 7.6a) showed that predators and *T. chilonis* could reduce LCM egg populations by >80% (Figure 7.6b). The manipulative experiment conducted in Samoa (Figures 7.6c-f) showed that abundances of *T. chilonis* in *N. baulus alba* eggs on *C. crepidioides* and in LCM eggs on the cabbage crop into which the weed was planted could be high but that they fluctuated over time (Figure 7.7). As the *T. chilonis* genetic studies demonstrated that a single population of *T. chilonis* attacked these different species in the Brassica- agroecosystem, it is reasonable to speculate that the *T. chilonis*, which were produced in large numbers by *N. baulus alba* eggs, moved to parasitise eggs of LCM. Whether or not this weed-non-pest host system can be effectively manipulated to improve parasitism of pest eggs in cabbage crops requires further research, but these data suggest that this would be worthwhile and a more effective way to successfully manipulate the *T.* chilonis population than field releases following mass production in the laboratory.

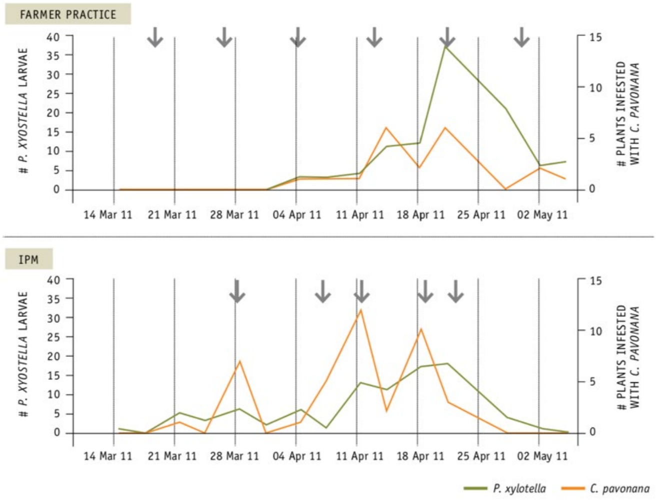

Figure 7.5: Effect of IPM ("combined Bt intervention threshold" -based on DBM density and proportion of the crop infested by LCM) on pest abundance when compared to farmers practice (representative data from an experiment conducted at Nu'u Crops research centre, Samoa). Grey arrows= applications of insecticide.

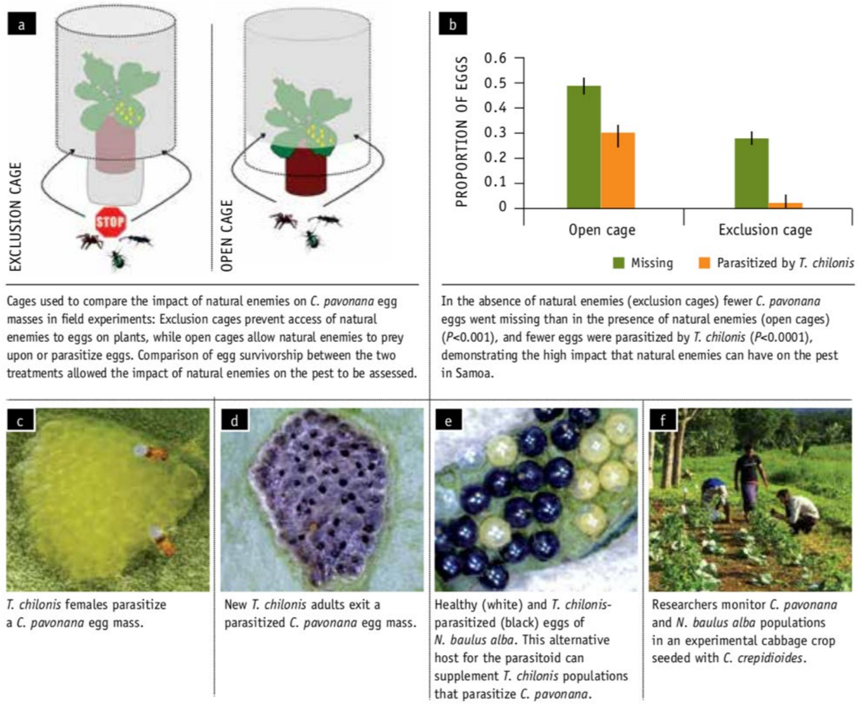

Figure 7.6: a) Design of natural enemy exclusion cages used to measure impact of natural enemies on *C. pavonana* populations in the field; **b)** impact of natural enemies (including *T. chilonis*) on *C. pavonana* in the field; **c)** *T. chilonis* attacking *C. pavonana* egg mass; **d)** *T. chilonis* exiting parasitised *C. pavonana* egg mass; e) *N. baulus alba* eggs parasitised by *T. chilonis*; **f)** sampling *T. chilonis* in field (see Fig 7.7 below).

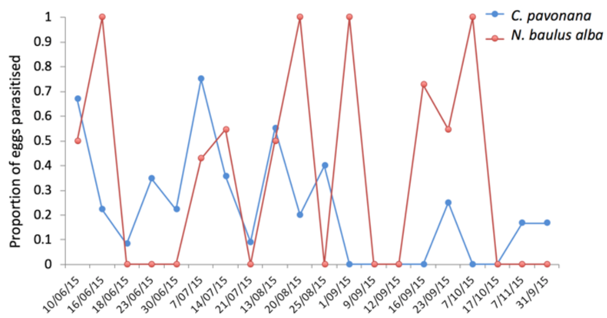

Figure 7.7: *T. chilonis* parasitism of *N. baulus alba* eggs on *C. crepidioides* plants intercropped with cabbage and corresponding *T. chilonis* parasitism of *C. pavonana* eggs on cabbage plants.

Activity 2.3: Cultural control methods for the management of *Nisotra basselae* in Solomon Islands developed and tested

Scientists at MAL, SPC and UQ designed several field experiments to test different cultural controls for the management of *Nisotra basselae*. The studies were beset by ongoing problems. The final experiment (completed June 2015) did not collect soil samples (to analyse egg densities); adult densities were low and no differences in foliar feeding beetle numbers were detected between treatments. Given the ongoing difficulties that this work suffered it was decided in 2015 that no further resources should be allocated to it. Consequently, no integrated strategy was satisfactorily tested for implementation in Solomon Islands.

Activity 2.4a: Evaluation of elicitors insect resistance in *Brassica* crops

Plant responses to herbivory and insect attraction and oviposition.

Female DBM did not discriminate between undamaged and herbivore-damaged common cabbage plants that were infested by DBM larvae for 6 h (Figure 7.8) but they did discriminate between Chinese cabbage plants in similar tests, showing a preference for undamaged plants over damaged plants (Figure 7.8). When larvae were removed from plants after 24 h of feeding (day 1), preferences for herbivore-damaged over undamaged common cabbage plants were observed for the first 6 days of testing but on the 7th day, no preference between undamaged and herbivore-damaged common cabbage plants was detected Figure 7.8). For Chinese cabbage, preferences for undamaged over herbivore-damaged plants were recorded until the 4th day of testing, but no preferences between undamaged and herbivore-damaged Chinese cabbage plants were detected thereafter (Figure 7.8)

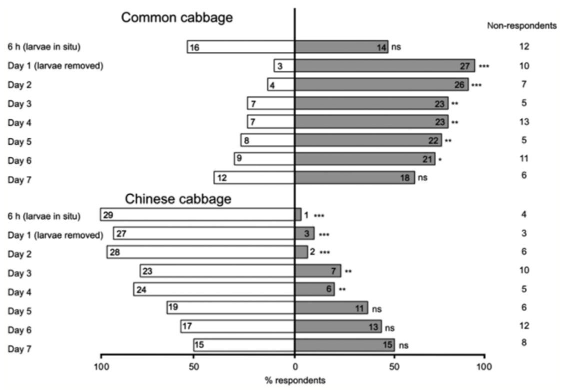

Figure 7.8: Preferences of mated female DBM when presented with intact (white bars) and induced (grey bars) common and Chinese cabbage plants in dual choice olfactometer assays. Numbers in bars are actual numbers of respondents. Asterisks represent statistical significance (G-tests: *0.01<P<0.05, **0.001<P<0.01, ***P<0.001, ns = not significant).

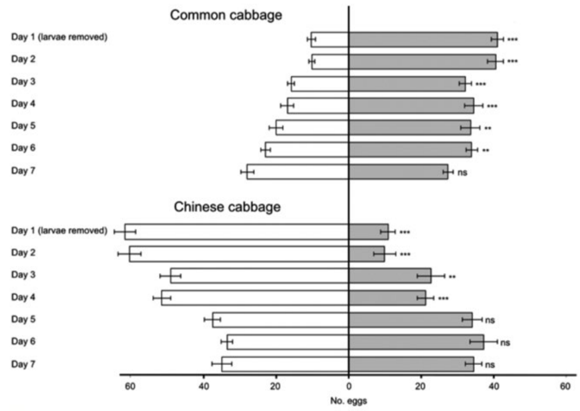

Figure 7.9: Daily oviposition of DBM on intact (white bars) vs. induced (grey bars) common and Chinese cabbage plants in choice tests (n = 22 for common cabbage, n = 10 for Chinese cabbage, per day). Asterisks represent statistical significance (t-tests: *0.01<P<0.05, **0.001<P<0.01, ***P<0.001, ns = not significant).

Thus, following herbivory, common cabbage plants become more attractive (Figure 7.8) and susceptible to DBM (more eggs laid on them, Figure 7.9) than undamaged plants and the effects were measurable for 6 days after herbivory ceased (Figures 7.8 and 7.9). In Chinese cabbage, herbivory induces insect resistance and herbivore-damaged plants were less attractive to DBM and they laid fewer eggs on them compared to undamaged plants for the next 4 days (Figure 7.8 and 7.9).

Effectiveness of plant responses to herbivory for manipulating insect distributions

The field experiment in Samoa showed that when cabbage plants were previously treated with JA (=plant elicitor) to indice the plant's response to herbivory, treated plants remained more attractive to ovipositing DBM for at least 4 days after treatment and eggs were concentrated on treated plants rather than on untreated plants (Figure 7.10). Thus, exploiting plant responses to herbivores offers a mechanism by which DBM oviposition preferences can be manipulated and crop plants selectively induced so that eggs can be concentrated on a few plants in the field. This offers an exciting new approach to trap cropping that should be explored further.

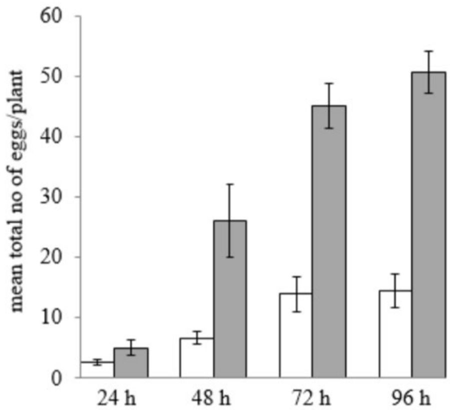

Figure 7.10 Cumulative number of DBM eggs laid on intact common cabbage plants (n = 8, white bars), and on JA-treated plants (n=6, grey bars), over 4 days in a field experiment in Samoa.

Plant responses to herbivory and the attraction of natural enemies

Naïve parasitoids [= parasitoids (1–2 days post-eclosion)] that had not foraged for or oviposited into a DBM host larva on a cabbage plant] were more attracted to host-damaged plants (feeding by 10 early 3rd-instar DBM larvae for 24 h immediately prior to test, larvae removed prior to olfactometer bioassay) than to intact plants ($P < 0.001$), but did not discriminate between DBM-damaged plants and non-host LCM-damaged plants (feeding by 10 2nd-instar LCM larvae for 24 h immediately prior to test, larvae removed prior to olfactometer bioassay) ($P > 0.05$) or DBM-damaged plants and plants treated with jasmonic acid (JA) (see Furlong et al, 2018 for detailed methods) (Figure 7.11). Experienced parasitoids (= parasitoids that had oviposited into a host DBM larva on a cabbage plant) were more attracted to DBM-damaged plants than LCM-damaged plants ($P < 0.001$) or plants treated with JA ($P < 0.001$). Although naïve parasitoids were more attracted to DBM-damaged Chinese cabbage plants than DBM-damaged cabbage plants ($P < 0.001$), parasitoids previously experienced on DBM on cabbage plants were more attracted to DBM-damaged cabbage plants than DBM-damaged Chinese cabbage plants in subsequent olfactometer assays ($P < 0.001$) (Figure 7.11). Thus, previous experience significantly affects the responses of *D. semiclausum* to the volatiles emitted by host plants in response to herbivory. Although naïve parasitoids are attracted to caterpillar damaged plants, they are unable to discriminate between plants damaged by host (DBM) and non-host (here LCM) larvae until they successfully attack a host DBM larva in the presence of the volatiles that its feeding induces the host cabbage plant to produce. Once it has done this it can discriminate between host-infested, non-host infested and JA-induced plants. This has implications the use of host plant induced volatiles in pest management as the research shows that parasitoid interactions with these chemicals is far more complex than previously realised and that recent experience overrides any intrinsic preference for specific volatiles.

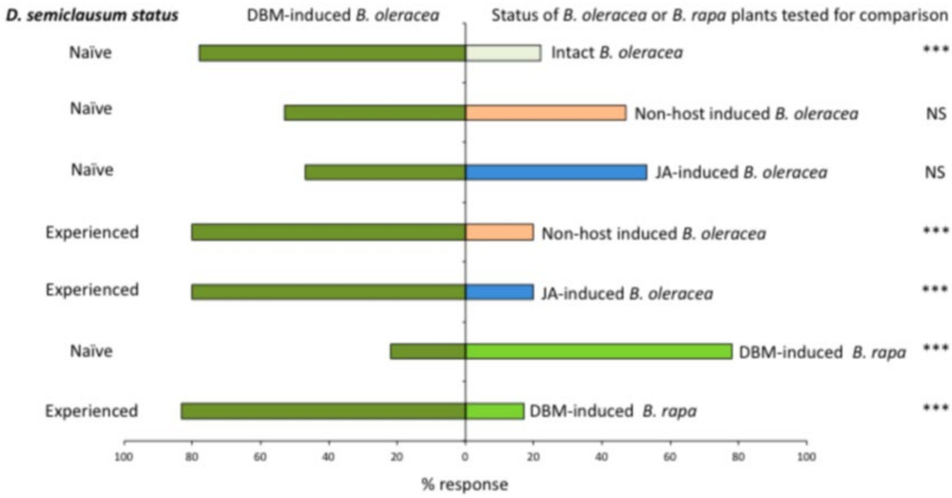

Figure 7.11: The intrinsic preferences and the effects of associative learning on the responses of the DBM parasitoid *Diadegma semiclausum* to different host plants (*Brassica oleracea* and *B. rapa*) infested with host (DBM) or non-host (LCM) larvae or which have been induced by the plant defence response elicitor jasmonic acid (JA).

Activity 2.4b: Evaluation of biochemical elicitors of pathogen resistance in Solanaceous crops

Evaluation of the efficacy of plant activators

Preliminary studies in 2013 showed that neutralized phosphorous acid (NPA), BION™, and ReZist™ could induce broad-spectrum effects to suppress diseases of tomato and pepper.

Glasshouse trials at WorldVeg-Taiwan in 2013 and 2014, evaluated the efficacy of five plant activators: neutralized phosphorous acid (1000 ppm); BION™ (100 ppm; active ingredient: Acibenzolar-S-methyl); ReZist™ (5000 ppm; active ingredient: Cu 1.75%, Mn 1.75%, and Zn 1.75%, with polyamines and natural plant extracts); potassium silicate (600 ppm); and chitosan (500 ppm) against tomato and pepper diseases (Table 7.7). The experiments indicated that the plant activators may trigger systemic acquired resistance (SAR, a plant-wide response that occurs following an earlier localized exposure to a pathogen) and suppress pathogen growth (Table 7.8). There were significant interactions between crop variety and pathogen isolate, suggesting host genotype and pathogen isolates could affect the overall control efficacy of plant activators in a field application.

Table 7.7. Efficacy of plant activators in suppressing diseases of pepper and tomato in glasshouse trials at WorldVeg-Taiwan, 2013 and 2014

Disease	Effect of activator on disease severity[1]				
	NPA[2]	BION™	ReZist™	Potassium silicate	Chitosan
Tomato late blight	+	+	+	-	-
Tomato early blight	-	-	+	-	-
Tomato bacterial spot	+	+	-	-	-
Pepper bacterial spot	-	+	-	-	+
Pepper Phytophthora blight	+	+	+	-	-
Tomato southern blight	+	+	+	-	-
Pepper southern blight	+	-	+	+	+

[1]+ = Significant reduction in symptom severity, - = no significant reduction in disease severity
[2]Neutralized phosphorous acid

Table 7.8: Concentrations of active ingredient tested and potential defence mechanisms induced.

Activator (concentration)	Active ingredients	Potential mechanism
NPS (1000ppm)	K_2PO_3	SAR/ growth suppression
BION™ (100ppm)	Acibenzolar-S-methyl	SAR
ReZist™ (5000ppm)	Chelated Cu, Mn and Zn	SAR/ growth suppression
Chitosan (500ppm)	Chitosan	SAR/ growth suppression
Potassium Silicate (600ppm)	K_2SiO_3	SAR/ growth suppression

In November 2016, a locally available commercial Phosacid systemic fungicide, Yates Anti Rot®, and a locally available fungicide (Bikpela) were tested for efficacy against foliar fungal diseases of three tomato varieties (Rose's Choice, MAL cherry and Local Red) in a replicated field trial in the Solomon Islands. The severity of bacterial spot (1.3- 2.8) was not significantly different from the control (2.8-4.5) (Table 7.14) and, for the unidentified fungal diseases, there was no clear pattern in the response of the different varieties to the different treatments (Table 7.9).

Table 7.9. Disease severity ratings of bacterial spot and unknown fungal diseases on tomato plants sprayed with Anti Rot and Bikpela

Fungicide treatment/ combinations	Variety	Disease severity rating‡	
		Bacterial Spot	Unknown fungal diseases
Anti Rot + Bikpela	Rose's Choice	2.3	2.0
Anti Rot + Bikpela	MAL Cherry	1.5	5.8
Anti Rot + Bikpela	Local Red	2.0	0.3
Anti Rot	Rose's Choice	1.5	0.8
Anti Rot	MAL Cherry	1.0	0.8
Anti Rot	Local Red	2.3	1.8
Bikpela	Rose's Choice	2.8	1.3
Bikpela	MAL Cherry	1.3	0.5
Bikpela	Local Red	1.3	1.0
Control	Rose's Choice	4.5	4.0
Control	MAL Cherry	4.5	1.5
Control	Local Red	2.8	0.5
P Value		0.724	0.175
CV (%)		83.	170

‡Disease severity scale rating: 1 = 1 – 5% leaf area affected and small leaf lesions, 2 = 6 – 15% leaf area affected and necrosis-restricted lesions, 3 = 16 – 30% leaf area affected and coalescent leaf lesions, 4 = 31 – 60% leaf area affected and edge-expanding lesions, 5 = 61 – 90% leaf area affected and drying leaf lesions, and 6 = 91 -100% leaf area affected, leaves blighting, extensive stem damage and/ or plant dead.

There was no treatment (Anti Rot, Bikpela combinations) effect on yield (P = 0.402) but yield was significantly affected by tomato variety (P< 0.001) (Figure 7.15) There was no interaction between treatment and tomato variety (P = 0.841) on cumulative tomato yields (Figure 7.12).

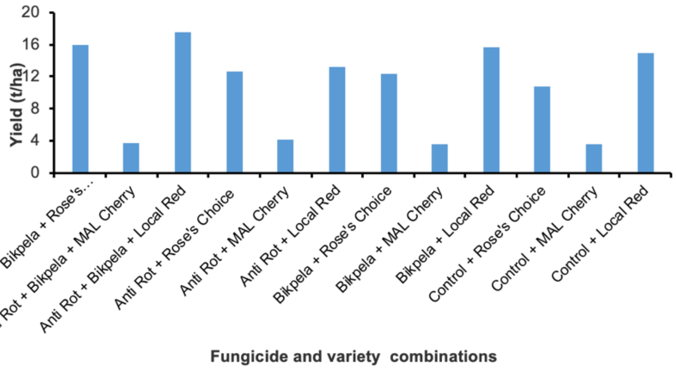

Figure 7.12: Cumulative marketable yield from harvests of three tomato varieties over the trial period in the Solomon Islands.

Activity 2.5: Develop improved techniques for disease diagnosis and monitoring in targeted vegetable crops

Development of paper-based protocol for molecular diagnosis of foliar diseases

Foliar diseases, particularly those causing brown necrotic lesions, are responsible for a considerable yield loss in Solanaceous crops and early blight, target spot, and bacterial spot on tomato, and *Cercospora* leaf spot, and bacterial spot on pepper can be devastating diseases in tropical and sub-tropical countries. The symptoms of these disease are very similar and reliable diagnosis is not possible by observation alone. The *Whatman FTA^{TM}* card was adopted as a simple and efficient tool to collect and preserve pathogen DNA from infected plant tissues and a diagnosis protocol developed to support remote diagnosis and disease surveys. This was validated by comparing diagnoses using two other methods, microscopy and isolation (Table 7.10). Samples of different diseases were collected in Taiwan during the rainy season. In some cases, more than one fungal pathogen was observed or isolated from the same lesion, indicating the presence of a complex pathogen population.

Table 7.10: Numbers of positive diagnosis of target diseases out of 20 samples present in tomato fields in Hsinyi, Nantou, Taiwan

Location	**Lesion type (Incidence)**	**Target disease** [1]	**Microscopy** [2]	**Isolation** [3]	**Molecular assay** [4]	
					ITS	***Xanthomonas* - specific PCR**
Lona Village (0.1ha)	Small brown lesion (100%)	Early blight	16	10	13	n.a.
		Target spot	9	2	0	n.a.
		Grey leaf spot	3	0	0	n.a.
		Other fungi	0	8	0	n.a.
		Bacterial spot [5]	n.t.	n.t.	n.a.	1/7
	Large brown lesion with concentric ring (100%)	Early blight	15	2	5	n.a.
		Target spot	11	6	2	n.a.
		Grey leaf spot	3	0	0	n.a.
		Other fungi	1	12	9	n.a.
		Bacterial spot	n.t.	n.t.	n.a.	0/4
Tungfu Village (0.3ha)	Dull brown lesion (10%)	Early blight	1	3	0	n.a.
		Target spot	1	0	0	n.a.
		Grey leaf spot	20	16	16	n.a.
		Other fungi	0	7	0	n.a.
		Bacterial spot	n.t.	n.t.	n.a.	1/4
	Scabby, dark brown lesion (100%)	Early blight	0	0	0	n.a.
		Target spot	0	0	0	n.a.
		Grey leaf spot	4	4	0	n.a.
		Other fungi	0	11	0	n.a.
		Bacterial spot	2/2	2/2	n.a.	20/20

Target diseases for the diagnosis included early blight caused by *Alternaria solani*, target spot caused by *Corynespora cassiicola*, grey leaf spot caused by *Stemphyllium* sp. and bacterial spot caused by *Xanthomonas* species. Non-target fungi diagnosed from various methods was recorded as "other fungi". "n.t.": not tested; "n.a.": not applicable

[2] Each lesion was diagnosed based on spore morphology or bacterial oozing

[3] Fungi isolated from lesions were identified based on colony and spore morphology using acidified potato dextrose agar plates at 25ºC.

[5] Bacterial spot diagnosis results were indicated as the positive number over the total tested sample number; (Note: The oozing test was conducted only on much fewer lesion due to the lack of samples).

In 2017, the diagnostic method was validated further using samples from Fiji and the Solomon Islands. A total of 20 samples collected from Sigatoka Valley in Fiji and 22 from East Honiara (KGVI area and Henderson) in Solomon Islands were tested (Table 7.11)

Table 7.11: Validation of molecular diagnosis protocol for foliar diseases of pepper and tomato using samples collected from Fiji and the Solomon Islands and transferred to FTA™ cards

				Specific PCR detection [c]						
NO	**Symptom/Crop**	**Source [a]**	**ITS Sequencing [b]**	**Aa**	**As**	**St**	**Cory**	**Pd**	**BS**	**Pathogen Diagnosed**
1	pepper leaf spot	A	*Cercospora capsici*	-	-	-	-	+	-	*C. capsici, Phoma destructiva*
2	pepper leaf spot	A	*C. capsici*	-	-	-	-	+	-	*C. capsici, P. destructiva*
3	pepper leaf spot	A	*C. capsici*	-	-	-	-	+	+	*C. capsici, P. destructiva , Xanthomonas sp.*
4	pepper leaf spot	A	*C. capsici*	-	-	-	-	+	-	*C. capsici, P. destructiva*
5	pepper leaf spot	A	*C. capsici*	-	-	-	-	+	-	*C. capsici, P. destructiva*
6	pepper leaf spot	A	*C. capsici*	-	-	-	-	-	-	*C. capsici*
7	pepper leaf spot	A	-	-	-	-	-	+	-	*P. destructiva*
8	pepper leaf spot	A	-	-	-	-	-	+	-	*P. destructiva*
9	tomato leaf spot	A	*Passalora fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
10	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
11	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
12	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
13	tomato leaf spot	A	*Pa. fulva*	-	-	-	+	+	-	*Pa. fulva, Corynespora cassicola, P. destructiva*
14	tomato leaf spot	A	*Pa. fulva*	-	-	-	+	+	-	*Pa. fulva, Co.cassicola, P. destructiva*
15	tomato leaf spot	A	*Pa. fulva*	-	-	-	+	+	-	*Pa. fulva, Co.cassicola, P. destructiva*
16	tomato leaf spot	A	*Pa. fulva*	+	-	-	+	+	-	*Pa. fulva, Co.cassicola, P. destructiva*
17	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
18	tomato leaf spot	A	*Cladosporum cladosporioides*	-	-	-	-	+	-	*P. destructiva, Cl. cladisporioides*
19	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
20	tomato leaf spot	A	*Pa. fulva*	-	-	-	-	+	-	*Pa. fulva, P. destructiva*
21	tomato leaf spot	B	*Ps. fuligena*	-	-	-	-	+	-	*Ps.fuligena, P. destructiva*
22	tomato leaf spot	B	*A. alternata*	-	-	-	-	-	-	*A. alternata*
23	tomato leaf spot	B	*Ps. fuligena*	-	-	-	-	-	-	*Ps. fuligena*
24	tomato leaf spot	B	*Ps. fuligena*	-	-	-	-	-	+	*Ps. fuligena, Xanthomonas sp.*
25	tomato leaf spot	B	*A. alternata*	+	-	-	-	-	+	*A. alternata, Xanthomonas sp.*
26	tomato leaf spot	B	*F. equiseti*	-	-	-	-	+	+	*Ps. fuligena, P. destructiva, Xanthomonas sp.*
27	tomato leaf spot	B	*Ps. fuligena*	-	-	-	-	-	+	*Ps. fuligena, Xanthomonas sp.*
28	tomato leaf spot	B	*Lectera colletotrichoides*	-	-	-	-	+	+	*P. destructiva, Xanthomonas sp.*
29	tomato leaf spot	C	-	+	-	-	-	-	-	*A. alternata*
30	tomato leaf spot	C	*Fusarium sp.*	-	-	-	-	-	-	?
31	tomato leaf spot	C	*Cl. cladosporioides*	+	-	-	+	+	-	*A. alternata, Co. cassicola, P. destructiva*
32	tomato leaf spot	C	*Nodulisporum sp.*	+	-	-	+	+	-	*A. alternata, Co. cassicola, P. destructiva*
33	tomato leaf spot	C	-	+	-	-	-	-	-	*A. alternata*
34	tomato leaf spot	C	*A. alternata*	+	-	-	-	-	-	*A. alternata*
35	tomato leaf spot	C	*Nigrospora sp.*	-	-	-	-	-	-	?
36	tomato leaf spot	C	*F. equiseti*	-	-	-	-	+	-	*P. destructiva*
37	tomato leaf spot	D	*Cl. cladosporioides*	+	-	-	-	+	-	*A. alternata, Cl. cladosporioides, P. destructiva*
38	tomato leaf spot	D	*Cl. cladosporioides*	+	-	-	-	-	-	*A. alternata, Cl. cladosporioides*
39	tomato leaf spot	E	-	-	-	-	-	+	-	*P. destructiva*
40	tomato leaf spot	E	-	-	-	-	-	+	-	*P. destructiva*
41	tomato leaf spot	E	-	+	-	-	-	-	-	*A. alternata*
42	tomato fruit rot	E	-	+	-	-	-	+	-	*A. alternara, P. destructiva*

[a] Disease samples collected from fields: A: Sigatoka, Nadroga-Navosa, Fiji; B TTM Farm, East Honiara, Solomon Islands, C. Zai Na Tina Farm, East Honiara, Solomon Islands, D. Kastom Garden Farm, East Honiara, Solomon Islands in August and E George Farm, Henderson, East Honiara, Solomon Islands in Oct 2016. Samples on FTA™ card were analyzed by WorldVeg/HQ in Feb 2017.
[b] Fungal internal transcriber spacer of rDNA was amplified by a universal primers ITS4/ITS5. The PCR product with one intense band was sequenced. The similarity was compared against the NCBI database through BLAST (Basic Local Alignment Search Tool) searches. The taxon name with maximum similarity scores (>99%) is shown.
[c] Specific PCR conducted by following specific primer combined with universal primer ITS4 was used to detect *Alternaria alternate* (Aa; 5'-CCAGCAAAGCTAGAGACA-3'), *Alternaria solani* (As;5'-TAGACCTTGGGGCTGGAAGAG-3'), *Stemphylium* sp (St; 5'-CAACCAAGGCTGATTCAAAG-3'); *Corynespora cassicola* (Cory: 5'-GTTTTGTTCAGACGTGTACTTC-3') and *Phoma destructiva* (5'-GCAAAGGCGAGACAAAC-3'),respectively. Moreover, a *Xanthomonas*-specific primer Xan7/X-gumD-fw (Mbega et.al, 2013) was used to detect bacterial leaf spot pathogen. More than one pathogen detected from the same sample was regarded as a co-infection. Tested samples with a positive reaction to a *Xanthomonas* specific primer was further differentiated into 4 species (*Xanthomonas euvesicatoria*, *X.vesicatoria*, *X. perforans* and *X. gardneri*) by using multiplex PCR described by Araujo et.al, 2012. However, none of the four common *Xanthomonas* sp. was identified.

Three pathogens (*C. capsici, Phoma destructiva, Xanthomonas sp*.) were detected from samples of chilli leaves collected from Sigatoka Valley, Fiji (#s 1-8; Table 7.11). BLAST analysis of 6 ITS sequences from samples with typical frog-eye symptoms confirmed *C. capsici* as the major causal agent. However, specific PCR showed the presence of *Ph. destructiva* in mixed infection in 5/6 of the *C. capsici* positive samples, while *Xanthomonas spp*. was also detected in one of the 5 samples.

Four known foliar pathogens (*Passalora fulva*, *Ph. destructiva, Corynespora cassicola*, and *Alternaria alternata*) were detected from 12 tomato leaf samples collected from Sigatoka Valley (#s 9-20; Table 7.11). BLAST analysis of ITS sequences consistently associated 11 of these samples with typical yellowish leaf mould symptoms with *Pa.*

fulva, and the remaining one with *Cladosporium cladosporioides*. Similar to the chilli samples, PCR with specific primers revealed the presence of many multiple or co-infections; all 12 samples tested positive for *Ph. destructiva,* four of these were also positive for *Co. cassicola* and one was positive for *Ph. destructiva*, *Co. cassicola* and A. *alternata*.

In Solomon Islands samples were collected from fields in East Honiara (i) TTM farm (#s 21-28), (ii) Zai Na Tina Farm (#s 29-36), (iii) Kastom Garden Farm (#s 37-38), and (iv) George Farm (#s 39-42). All samples were collected from tomato leaves except for sample # 42 which was collected from a tomato fruit at George farm. Visual inspections indicated that foliar diseases appeared much more complex in Solomon Islands compared to Fiji. At TTM farm, 4 pathogens comprising *Xanthomonas sp*. (5 out of 8 samples tested), *Psuedocercospora fuligena* (4/8), *A. alternata* (2/8) and *Ph. destructiva* (3/8) were diagnosed, confirming the observation of symptoms of black mould and bacterial spots. However, from the other 3 farms, the diagnosis by ITS sequencing did not match the symptoms observed. It is likely that *Ph. destructiva* was the primary pathogen in most cases and that the other fungi detected were generally secondary pathogens on the diseased lesion. Other unknown causes might also be associated with the dark brown lesion symptoms observed. The study confirmed the presence of several important foliar diseases on pepper and tomato in Fiji and Solomon Islands. The results reflected the complicated nature and pathogen diversity of foliar diseases on the two crops. Although the survey was limited in the number of samples, it suggests that pepper *Cercospora* leaf spot caused by *C. capsici*, tomato leaf mold caused by *Pa. fulva*, tomato black mould caused by *Ps. fuligena*, and tomato *Phoma* leaf spot caused by *Ph. destructiva* are the major concerns in both countries. The accurate pathogen diagnosis is vital for disease management in crops and the FTA™ card-based diagnostic protocol can be used to determine the main pathogens associated with foliar diseases on pepper and tomato. Similar methods can be applied to facilitate surveys of the other target diseases in the future.

<u>Improvement of molecular diagnosis of *Colletotrichum* spp., causal agent of pepper anthracnose</u>

A paper-based (FTA™ card) protocol for the molecular diagnosis of *Colletotrichum* species associated with pepper anthracnose using has been developed (Appendix 3) and successfully used with PCR based diagnostics and species-specific primers. The protocol was used to identify 13 isolates of *Colletotrichum* species collected from chilli peppers showing anthracnose symptoms in Fiji. Based on the ITS-RFLP patterns, the majority of the 13 isolates were identified as *Colletotrichum acutatum*, bout one isolate was identified as *C. gloeosporioides* (Appendix 3). This confirms earlier results that *C. acutatum* is the predominant pathogen causing chilli anthracnose in Fiji. The protocol was also used to diagnose anthracnose during the 2013 sweet pepper variety trial conducted in the Solomon Islands. Plant tissues were collected from fruits of ten varieties showing anthracnose-like symptoms and applied onto FTA™ cards. *C. acutatum* was diagnosed from only one of the varieties, AVPP0119. The other symptoms were likely caused by sun scald. The same sampling protocol was applied to diagnose a disease that caused necrotic lesions on sweet pepper at Sigatoka Research Station in Fiji, September 2013. Tissues of diseased lesions were squashed onto an FTA™ card and using species-specific primer pairs, the disease was diagnosed as bacterial spot caused by *Xanthomonas euvesicatoria*.

Objective 3. To develop integrated approaches for intensifying vegetable production (Lead organization: WorldVeg with SPC)

<u>Activity 3.1:</u> <u>Use of standard screening procedures (developed in PC2005/077) to field evaluate improved varieties of Solanaceous crops for quality and market potential, as well as the prospects of extending production seasons in Fiji, the Solomon Islands, Samoa, and Tonga.</u>

Potential varieties selected based on a set of defined criteria and seeds acquired for field trials

Using the protocols developed (Appendices 4 and 5) three field trials were conducted in both Fiji and the Solomon Islands over three regular cropping seasons from 2012 to 2015. During each of the three trial stages, varieties were eliminated using two selection criteria: field performance (pest/ disease tolerance and yield), and fruit quality and marketability (taste, appearance and firmness). A total of 11 WorldVeg lines, 3 cherry lines (Table 7.12) and 8 fresh market lines (Table 7.13) were evaluated.

Table 7.12: Yield, taste rating, growth habit, fruit characteristics and pest/disease rating of cherry tomato varieties in Fiji and Solomon Islands

Entry	Total yield (t/ha)		Taste score		Growth habit	Fruit characteristics		Pest/ disease score[Ŧ]	
	Fiji	Solomon Islands	Fiji	Solomon Islands		Shape	Colour	P	D
CLN2071B	58ab	22bc	5	5	Indeterminate	Oblong	Orange	3	1
CLN2071D	45bc	34a	5	5	Indeterminate	Oblong	Orange	1	1
CLN2463E	39c	24b	4	5	Semi determinate	Oblong	Red	3	1
Season Red*	69a	NT	4	NT	Semi determinate	Round	Red	1	1
Local Red*	NT	41a	NT	4	Indeterminate	Round	Red	1	1

Different letters within columns indicate a significant difference between treatments (P< 0.05, LSD test)
Notations: NT = Not tested, Entry in bold font was selected by both countries for official release, *Local control variety, [†]Taste rated on a scale of 1 – 6 (1 = poor to 6 = excellent), [Ŧ]Pest (P)/disease (D) rated on scale 1 – 3 (1-slight to 3-severe)

Table 7.13: Yield, taste rating, growth habit, fruit characteristics and pest/disease rating of fresh market tomato varieties in Fiji and Solomon Islands

Entry	Total yield (t/ha)		Taste score		Growth habit	Fruit characteristics		Pest/ disease score[Ŧ]	
	Fiji **	Solomon Islands	Fiji	Solomon Islands		Shape	Colour	P	D
CLN3205A	44	11b	5	5	Semi determinate	Plum	Red	1	1
CLN3078I	54	7bc	5	5	Indeterminate	Oval	Red	3	1
CLN3150A-5	55	NT	5	NT	Semi determinate	Plum	Red	1	1
CLN3212A	51	NT	5	NT	Semi determinate	Oval	Red	1	3
Raising Sun #2*	60	NT	5	NT	Determinate	Round	Red	2	1
CLN2585D	NT	17a	NT	5	Semi determinate	Oval	Red	2	2
CLN3241I	NT	8bc	NT	5	Semi determinate	Round	Red	2	1
CLN3241A	NT	5cd	NT	5	Determinate	Oval	Light red	1	1
CLN3078L	NT	8bc	NT	5	Determinate	Oval	Red	1	3
Grosse Lisse*	NT	1d	NT	5	Indeterminate	Round	Red	1	1

Different letters within columns indicate a significant difference between entries (P< 0.05, LSD test),
**Means of entries not significantly different according to LSD test at P< 0.05; Notations: NT = Not tested,
Entry in bold font was selected by each country for official release, *Local control variety, [†]Taste rated on a scale of 1 – 6 (1 = poor to 6 = excellent), [Ŧ]Pest/disease rated on scale 1 – 3 (1 = slight to 3 = severe)

Suitable adapted varieties of Solanaceous crops for regular season production identified

Variety evaluation trials conducted were conducted over three regular seasons in Fiji and the Solomon Islands (Tables 7.14- 7.16). The work resulted in the selection and official release of four OP tomato varieties and one capsicum variety.

i) Selected varieties in Fiji. Two tomato varieties (1 fresh market and 1 cherry) were selected from the promotion trial in 2014. The fresh market tomato (CLN 3150A-5), locally a named "Melrose" was released by the Ministry in 2015 and the cherry tomato (CLN 2071D), locally known as "Rio Gold" was released in 2016. Both varieties are high yielding, produce well-shaped fruit and have a taste that is preferred by local market. "Melrose" is homozygous for the Ty-2 and Ty-5 genes that confer resistance to Tomato Yellow Leaf Curl (begomoviruses) and for the Tm^{22} allele that confers resistance to Tobacco Mosaic Virus. "Rio Gold" is resistant to bacterial wilt and of fusarium wilt race 1. Three field trials to evaluate sweet pepper varieties were conducted over three cropping seasons in Fiji (Table 7.14) but no variety was selected for official release. The Ministry intended to conduct further evaluation trials at different locations in Fiji prior to selecting a variety but these activities were not completed. In order to do this, seeds will again need to be sourced from the WorldVeg genebank.

ii) Selected varieties in the Solomon Islands. Three tomato varieties (2 fresh market and 1 cherry) and one OP sweet pepper line were officially released in Solomon Islands. The fresh market tomato varieties (CLN 2585D and CLN 3078I) are locally known as "Rose's Choice" and "MAL Fresh" respectively, the cherry tomato (CLN 2071D) is locally known "MAL Cherry" and the capsicum variety (AVPP 1114) is known as "MAL Wonder". "Rose's Choice" showed some resistance to bacterial wilt, Tobacco Mosaic Virus, fusarium wilt race 1 and Tomato Yellow Leaf Curl. "MAL Fresh" has some resistance to bacterial wilt and is homozygous for the Ty-2 and Ty-3 genes for resistance to Tomato Yellow Leaf Curl (begomoviruses) and the Tm^{22} allele for resistance to Tobacco Mosaic Virus. MAL Cherry, known as Rio Gold in Fiji, is anticipated to also show resistance to plant diseases in Solomon Islands. The sweet pepper variety MAL Wonder is resistant to Potato virus Y (PVY), and is also high yielding with fruit colour, shape and taste accepted by local consumers.

Overall, the variety trials conducted in Fiji and the Solomon Islands showed that the new improved varieties performed well under growing conditions in the Pacific. Yields were comparable to local check varieties (fresh market and cherry tomato) in each country. Nonetheless, GAP and timely management need to be addressed to improve production further. The release of four new improved varieties (2 in Fiji and 3 in Solomon Islands), provides farmers with access to high yielding varieties, as the varieties are either indeterminate and semi determinate in growth habit, the number of harvests will also be greater.

iii). Variety trials in Samoa and Tonga. Variety trials in Samoa (varieties mixed up) and Tonga (tomato not a priority crop as many varieties are imported) were discontinued after the confirmation and observation trial stages.

Table 7.14: Marketable yield (t/ha), growth habit and comments by local tasters on cherry tomato lines evaluated in Fiji (on station and on farm) and the Solomon Islands

		Fiji			SI
Entry	Comments	KRS	SRS	Qereqere	Henderson
CLN 2463E	*Red; Semi determinate (SD)* FJ: attractive, nice flavor, good for marketing SI: attractive, excellent taste, good for	1.1c[2]	5.6a	3.0a	12.4a
CLN 2071D	*Red to orange; indeterminate (ID)* FJ: attractive shape and color, bitter taste, good for salad	5.3b	4.7a	2.6a	n.t
CLN 2071B	*orange; ID* FJ: appealing shape but weird color	8.4a	7.7a	3.5a	n.t
Season Red[1]	*Red; SD* FJ: small size, good taste but color not	4.7b	9.2a	7.0a	nt
Tiny Tim[1]	*Red; Determinate (D)* SI: poor growth; no marketable fruits produced, taste quite good	nt	nt	nt	0.0b

[1]Local cultivars: Season Red, a commercial hybrid cultivar of Known You Seeds in Taiwan and distributed by Hop Tiy Ltd. in Fiji; Tiny Tim, a commercial cultivar of Yates and distributed by Island Enterprise Ltd. in Solomon Islands
[2]Means followed by different letters within each column are significantly different according to the Least Significant Difference (LSD) Test at $p < 0.05$, nt: not tested

Table 7.15: Marketable yield (t/ha) growth habit, fruit description and comments by local tasters on fresh market tomato lines evaluated in Fiji (on station and on farm) and the Solomon Islands

		Fiji			SI
Line/ variety	Comments	KRS	SRS	Qereqere	Henderson
CLN2585D	*Red, oval shape; Semi Determinate (SD)* SI: large fruit, good taste, very good for marketing	nt	nt	nt	16.6a
CLN3205A	*Red, plum shape; SD* FJ: juicy with strong flavour, good for marketing.	4.9bc[2]	6.3bc	5.1a	10.5b
CLN3241I	*Red, large round shape; SD* FJ: good taste, juicy with smooth texture SI: large fruit size, good for marketing	5.9bc	8.5ab	2.6a	8.4bc
CLN3078I	*Red, long oval shape; indeterminate (ID)* FJ: good taste, firm flesh, good for marketing SI: good taste, colour, sweet juicy flesh, good for marketing	5.9bc	7.3bc	5.1a	6.7bc
CLN3241A	*Light red, oval shape; Determinate (D)* SI: good taste, shape, size; good for marketing	nt	nt	nt	4.8cd
CLN3078L	Red, large and oval shape; D or SD FJ: good shape, size, taste and colour SI: good for cooking and salad but not juicy	4.3c	4.0c	2.6a	7.9bc
Grossel[1]	*Red, round shape; ID* SI: good taste but not juicy or sweet	nt	nt	nt	0.7d
Raising Sun #2[1]	Red, oval shape; *ID* FJ: attractive fruit, delicious taste, excellent for the market	10.2a	11.6a	7.5a	nt
CLN3150A5	*Red, plum shape; SD* FJ: good size/ shape; juicy with strong flavor; good for market	8.3ab	9.0ab	6.1a	nt
CLN3241G	*Light red, oval shape; SD* FJ: good appearance and color	7.8ab	5.2bc	nt	nt
CLN3212A	*Red, large oval shape; SD* FJ: very good taste	7.7ab	7.8b	2.2a	nt

[1]Local check cultivar
[2]Means followed by different letters within columns are significantly different within each column for each country according to the Least Significant Difference (LSD) Test at $p < 0.05$
nt: not tested

Adapted varieties for extending the production season of each crop identified

i) Off-season tomato variety evaluation trials for extending the production season in Fiji

Six tomato varieties (4 hybrids and 2 OP) were evaluated against a local check variety in two off-season field trials at Sigatoka Research Station (Table 7.17). Target spot and leaf mould the predominant pathogens the hybrid variety “Sensation” was highly susceptible to foliar diseases. In the initial stage of crop growth, the only insect pest found was leaf miner, while flea beetle infested plants later in the trial. In the early fruiting stage, there was a high infestation of fruit-borer, but it was effectively controlled by Bt. At harvest, brownish specks were observed on fruits of CLN 3212A and CLN 3575-F1, which rendered them unmarketable. Similarly, during harvest Grace and CLN 2585D suffered high incidences of blossom end rot, resulting in the fruits being discarded. Bird damage was the major cause of unmarketability of fruits during harvest. The total marketable yield of the varieties (3 plots/variety) ranged from 11 kg to 20.8 kg. The two OP lines produced the lowest yields (11kg and 11.4kg) (Table 7.17). For the hybrid varieties, Grace produced 20.1 kg, a similar yield to the local check variety, Raising Sun #2, which produced 19.1 kg (Table 7.17).

Table 7.16: Marketable yield (kg) fruit description and comments on taste and appearance for sweet pepper lines evaluated in Fiji and the Solomon Islands

Line/ variety	Fruit description and comments (FJ: Fiji; SI: Solomon Islands)	FJ	SI
AVPP1112	*Light green-red, bell shape* FJ: good taste and size, good for marketing	10.6	nt
AVPP1113	*Green-red, bell shape* FJ: large size fruit, good for marketing	25.6	nt
AVPP1114	*Green-yellow, bell shape* FJ: good shape with excellent taste, good for marketing SI: good taste with marketable fruit size	15.2	9.4
C05483	*Green-red, bell shape* FJ: very pungent with strong taste but small size fruits SI: good taste and suitable for market	14.2	7.2
Blue Star[1]	*(Description not provided)* FJ: large fruit with sweet taste	12.5	nt
Yolo Wonder[1]	*Dark green, bell shape* FJ: good appearance and taste but not tasty SI: good strong smell and flavour and the dark green colour is liked	12.7	5.6
AVPP0701	*Green-red, long bell* FJ: attractive colour, good for salad and marketing SI: suitable for salad and good for market	20.8	8.2
VI046956/ PBC 762	*Long green-red, long bell shape* FJ: good size and appealing colour, thus highly recommended for marketing SI: good shape and size and suitable for local market	20.0	6.4
AVPP1119	*Green-yellow, bell shape* FJ: appealing colour, excellent firmness with sweet taste SI: poor flavour, not good for market	12.8	5.0
AVPP1115	*Green-yellow, bell shape* FJ: good taste when raw as well as cooked, fruits perfect for marketing SI: good taste and shape, good for market	19.0	4.9
AVPP0121	*Light green-red, bell shape* FJ: unattractive colour with lots of blemishes on fruit but still tastes good SI: watery but very juicy	19.6	5.7
AVPP9814	*Green-red, bell shape* FJ: good shape and size, good taste but not so pungent SI: excellent fruit with good taste, good for market	6.9	6.7

[1]Local check cultivar
nt: not tested

Table 7.17: Marketable yield (kg) of tomato varieties evaluated in offseason field trial at Sigatoka Research Station

Line/ Variety	Type	Total marketable yield (kg)
Grace	Hybrid	20.76 a
CLN2585D	OP	10.99 d
CLN3212A	OP	11.42 d
CLN3735 F1	Hybrid	16.21 bc
Sensation	Hybrid	17.44 ab
King Kong #2	Hybrid	12.93 cd
Raising Sun #2[Ŧ]	Hybrid	19.06 ab

Means within the column followed by the same letters are not significantly different according to Least Significant Difference (LSD) Test at $p < 0.05$
[Ŧ]Local check variety

ii) *Tomato grafting for off-season production in Solomon Islands and Fiji*

Two grafting field trials were conducted during the rainy season of 2014. They showed that a high survival rate (>50%) of the two tomato varieties on the three eggplant root stocks could be achieved at the nursery stage (Table 7.18).

Table 7.18: Survival of different eggplant rootstock and tomato seedlings at the nursery stage

Treatment combination		Grafts		
Egg plant rootstock	Tomato	Number of grafts	No seedlings surviving	Survival rate (%)
EG203	CLN 2585D	22	21	96
EG203	Grace	29	23	79
EG195	CLN 2585D	87	63	72
EG195	Grace	101	76	75
EG190	Grace	51	38	75
EG190	CLN2585D	55	48	87

When heavy rainfall fell continuously for three days, resulting in waterlogging in furrows of plots in the field, non-grafted plants wilted and some eventually died while all but one of the grafted survived.

A replicated trial showed that grafted plants had higher survival rates compared with non-grafted plants after heavy rainfall and subsequent flooding. In April 2014, heavy rainfall for three days, resulted in flooding of the field and caused waterlogging for 2 to 3 days. Seven days after waterlogging, non-grafted tomato plants wilted and eventually died meaning that there was no harvest. All grafted tomato plants recovered from the waterlogging, survived and produced fruit which were harvested (Table 7.19). The tomato variety 'CLN 2585D' grafted onto EG190 rootstock produced the highest total number of fruit, the greatest number of marketable fruit, highest total fruit weight and greatest weight of marketable fruit (Table 7.19).

Table 2.19: The total number of fruits, number of marketable fruits, total fruit weights and marketable weights of fruits from four of grafted tomato crops that survived water-logging

Treatment combination					
Eggplant rootstock	Tomato	No. of fruit harvested	Total fruit weight (g)	No. of marketable fruit	Weight of marketable fruit (g)
EG195	CLN2585D	59.7 ab	2956.7 ab	45.3 ab	2770.0 ab
EG190	Grace	47.0 b	2370.0 b	32.7 abc	2220.0 ab
none	CLN2585D	0.00 c	0.0 c	0.0 c	0.0 c
EG195	Grace	57.7 ab	2286.7 b	29.3 bc	2126.7 b
EG203	CLN2585D	83.7 ab	4070.0 a	59.0 ab	3566.7 ab
EG190	CLN2585D	95.0 a	4026.7 a	66.3 a	3753.3 a
none	Grace	0.0 c	0.0 c	0.0 c	0.0 c
EG203	Grace	58.0 ab	2360.0 b	28.7 bc	2270.0 ab

Means within the same column followed by the same letter are not significantly different at $p<0.05$.

In Fiji, hands-on sessions on grafting tomato scions onto eggplant rootstocks were conducted. However, when grafted seedlings were placed in a locally constructed healing chamber, low survival rates (< 50 %) were achieved. Consequently, no grafting field trials were conducted in Fiji.

Activity 3.2: Field evaluation of ICM practices for improved pest and disease management in year-round vegetable production in Fiji, the Solomon Islands, and Samoa.

Farmer survey in Fiji to understand vegetable farmers' perceptions on production and marketing

A farmer survey interviewed 80 vegetable farmers from the Sigatoka Valley, Cane Coastal area, and Koronivia on Viti Levu in September and October 2012. The key findings were (i) tomato, eggplant and cabbage are the three main crops, (ii) use of chemical fertilizers and pesticide are common, (iii) hand watering (using buckets or watering cans) is the most common irrigation method, (iv) the main production constraints are pest damage and climate (v) most farmers harvest tomato in the afternoon and grade them before transport in wooden crates, (vi) farmers sell their produce themselves (41%), through middlemen (43%) or through another vendor (16%) and (vii) prices for all crops except eggplant (these are stable throughout the year) are lower during the regular cropping season (June to October). The survey also indicated that improvements to soil fertility and IPM extension are necessary for the intensification of vegetable production. Pest management issues beyond the use of pesticides (e.g. crop rotation and identification of pests and diseases) required intervention. Following the survey, it was concluded that for long-term support to vegetable production measures need to be taken to mitigate flooding. The survey also showed that plans to work on the postharvest handling of tomatoes were justified. The survey report was published in 2013 as a joint publication with SPC and MOA (Appendix 7).

Seedling production technology developed in PC/2005/077 adapted and improved

Differences in tomato seedling (Raising Sun #2) height, number of leaves and root length were investigated in different potting media (Table 7.20). Seedlings in mixes containing compost, coconut husk and Thrive Premium Potting Mix (Yates) grew better than seedlings grown in other media (Table 7.20).

Table 7.20: Seedling height (cm), number of leaves and root length (cm) in different potting media treatments.

Potting mix	Average seedling height (cm)				Number of leaves				Root length (cm)
	13 days	15 days	17 days	23 days	13 days	15 days	17 days	23 days	
A: compost and coconut husk	6.8	6.0	6.1	6.4	2.8	5.4	5.6	6.42	12.0
B: compost, coconut husk, thrive	**6.8**	**8.0**	**9.1**	**9.3**	**3.4**	**7.2**	**10.6**	**9.3**	**20.0**
C: compost, coconut husk, styrofoam	5.1	4.6	3.5	4.2	1.6	3.2	4.8	4.2	11.0
D: compost, coconut husk and sand	3.44	5	3.7	3.2	1.6	1.6	3.4	3.2	12.0
E: compost, thrive and sand	**7.4**	**7.5**	**6.9**	**8.9**	**4.0**	**6.6**	**8.6**	**8.9**	**22.0**
F: compost, styrofoam and sand	n.m	n.m	n.m	n.m	n.m	n.m	n.m	n.m	9.6
G: compost and sand	2.3	2.4	3.3	3.1	0.4	1.0	1.4	3.1	8.9
H: soil and coconut husk	4.4	4.0	3.8	4.2	1.4	3.8	5.2	4.2	9.0
I: soil, coconut husk and thrive	**6.7**	**7.1**	**7.1**	**13.2**	**2.8**	**7.0**	**10.4**	**13.2**	**24**
J: soil, coconut husk and styrofoam	3.3	3.7	2.4	3.0	0.4	2.0	2.2	3.0	10.0
K: soil, coconut husk and sand	3.5	3.5	2.6	4.2	1.0	2.4	3.4	4.2	10.5
L: soil, coconut husk and sand	3.6	3.6	3.3	4.3	2.0	2.0	4.4	4.3	10.3
M: soil, thrive and sand	**6.7**	**6.9**	**7.9**	**9.2**	**2.0**	**6.4**	**8.6**	**9.2**	**20**
N: soil, styrofoam and sand	n.m	n.m	n.m	n.m	n.m	n.m	n.m	n.m	10.0
O: soil and compost	4.3	3.8	4.4	4.7	1.6	2.2	4.4	4.7	10.6
P: peat moss and soil	**4.2**	**4.7**	**6.0**	**7.2**	**2.8**	**6.2**	**6.0**	**7.2**	**16.0**
Q: soil alone	4.2	4.0	3.4	4.3	1.4	2.8	3.4	4.3	10.0

n.m: not measured; Entries highlighted in bold font were selected for further evaluation

Potting media containing coconut husk and thrive mixed with soil, improved both germination and growth of the tomato seedlings. This could be due to the nutritional status of the combined substrates in the potting media which may be very low in soil alone. Based on these results, five potting media were selected for further evaluation. This showed that potting mix that contained equal proportions of soil, grated coconut husk and Thrive Premium Potting Mix had good water retention capacity and that tomato seedlings grown in this medium were taller, had more leaves and vigorous, healthy root development. This potting medium was selected for recommendation to growers in the Sigatoka Valley for raising tomato seedlings in plug trays.

Simple drip irrigation kits evaluated for effectiveness and durability (in dry areas)

Drip irrigation kits were purchased and stored in the Sigatoka ICM Project-office but irrigation trials were not conducted. Ostensibly this was because “drought” conditions did not occur during the project, but it is not clear why the work was not done. The irrigation kits are available and can be used in HORT/2016/185.

Suitability of protective structures for extending production season determined (in wet areas) in Fiji

This activity was undertaken in collaboration with PARDI, the trial design for the protective structure was prepared by a PARDI project scientist. The crops initially planted for investigation under the structure were tomato, capsicum and cucumber (Figure 7.13). Two off-season production runs were completed between November 2015 and April 2016. Cropping techniques including pruning, trellising and irrigation systems were demonstrated to MOA staff and farmers to encourage adoption of the practices. In 2017, trials under the protective structure at Sigatoka Research Station were continued under the PARDI project.

Figure 7.13: Capsicum, tomato and cucumber varieties grown for preliminary observation under a protective structure at Sigatoka Research Station.

Utility of insect exclusion nets as a component of Brassica IPM on small holdings verified.

An experiment conducted in Fiji in 2014, showed that covering the plots with Veggie net from transplanting to post cupping gave the highest total marketable weight of 23.9 kg for 20 sampled plants, but this was not significantly different to yields obtained for covering the plot from pre-cupping to post-cupping, and application of Bt, with marketable weights of 21.9 kg and 18.2 kg (20 plants per treatment), respectively (Table 7.21). No marketable harvest was obtained from the uncovered control plots due to significant insect damage. The results indicated that covering the plots with Veggie net and application of Bt are both effective methods to control insect infestation and farmers can produce high quality Brassicas for a marketable yield.

Table: 7.21: Total marketable weight (kg) of cabbage managed by different treatments in netting experiment in Fiji.

Treatment (code and description)	Total marketable weight
NT1: Veggie net over plot at transplanting to post cupping	23.1a
NT2: Veggie net over plot from pre-cupping to post cupping	21.9a
Bacillus thuringiensis (Bt)	18.2a
Control: Uncovered plots	0b

Means within the column followed by the same letter are not significantly different at $p < 0.01$

In the Solomon Islands, results were similar to those in Fiji; plants raised under the net and those treated with Bt suffered reduced insect compared with the control. Marketable yield was also high for these treatments, but no marketable yield was obtained for the control Table 7.22) due to high infestations by large cabbage moth (*Crocidolomia pavonana*) and diamondback moth (*Plutella xylostella*).

Table 7.22: Total marketable weight (kg) of cabbage for different treatments recorded at harvest at Betikama Farm, Honiara

Treatment (code and description)	Total marketable weight
NT1: Veggie net over plot at transplanting to post cupping	14.3a
NT2: Veggie net over plot from pre-cupping to post cupping	9.7a
Bacillus thuringiensis (Bt)	13.9a
Control: Uncovered plots	0b

Means within the column followed by the same letter are not significantly different at $p < 0.05$

Activity 3.3: Field evaluation of soil management approaches (including use of biochar, legumes as rotation crops, and balanced fertilization) to promote sustainable soil health.

Current status of soil health determined in pilot sites

The soil health survey (Appendix 8) showed that all 15 farms investigated suffered from poor soil fertility, low organic matter, labile carbon, and low soil microbial activity. Application of cultural practices to increase soil fertility and organic matter will improve the soil health of the surveyed sites.

Long-term field trials with legume rotation and SST/balanced fertilization conducted

Following the first rotations with the selected legume crops (mucuna, cowpea and yard long bean) soil analysis (Table 7.23) was completed in October 2015. The different legumes had similar effects on the soil, but total carbon and nitrogen levels remained low (Cf ideal values in Table 7.21). Continuous addition of farm residues and compost may contribute to increasing soil organic matter (SOM), thus improving total carbon in the soil and continued use of legumes should increase nitrogen levels.

Table 7.23: Soil analysis results for plots with and without legume rotation in the soil health trial at Sigatoka Research Station

Plot/ legume	pH	Electrical Conductivity mS/cm	Total C (%)	Total N (%)	Olsen Available Phosphorus (mg/kg)	Ca (me/100g)	K (me/100g)
Cowpea	6.9	0.04	1.7	0.08	75	14.94	1.53
Yard long bean	6.8	0.04	1.6	0.16	93	13.89	1.53
Mucuna	6.8	0.05	1.9	0.14	79	14.41	1.72
Grass fallow	6.8	0.04	1.7	0.11	78	16.89	1.75
Ideal value (quality control values used in analysis)	5.6 – 6.6	0.4 - 0.8	4 - 10	0.3 - 0.6	20 - 30	2.0 - 10	0.3 - 0.6

Activity 3.4: Research station field-days and on-farm demonstrations to promote adoption of technologies.

Extensive promotion of adapted varieties to vegetable growers during fiel- days

i) Field days in Fiji. Two field days were jointly organised by SPC, WorldVeg and MOA staff at Sigatoka Research Station on 30 September 2015 and 14 October 2016 to officially released two selected tomato varieties. A total of 116 people (23 females and 93 males) representing the private and public sectors, and farmers/farmer groups from different parts of Viti Levu attended the event in 2015. The chief guest was Assistant Minister for Agriculture, Honourable Joeli Cawaki. Participants visited the demonstration plots to see how the new variety was performing in the field and view a GAP demonstration (Figure 7.14). During the field visit, the participants could ask questions related to crop management practices and other information related to tomato production. Most farmers admired the firmness of ripe Melrose fruits, an important characteristic which may contribute to reducing damage on fruits during handling and transportation to the market.


Figure 7.14: A field day participant inspecting ripe fruits in the field (left) and Project staff, Mr. Mani Mua demonstrating how to tie a tomato plant to the stake (right)

Information distributed to participants during the event include a pamphlet on “Growing Tomato for Cash” prepared by MOA and a Research Release Note containing information on crop management practices and cost benefit analysis for the Melrose variety, jointly prepared by WorldVeg and MOA. To conclude the official launch of the variety, 211 seed packets of Melrose were distributed to participants. To continue Melrose seed production and distribution, the 1,200 flowering/ fruiting plants in the demonstration were handed over to the Principal Research Officer after the release event. A second field day to officially launch cherry tomato line CLN 2071D (locally known as Rio Gold), coincided with Fiji’s World Food Day celebration at Ni School in Suva on 14 October 2016. The variety release event program was jointly organized by SPC and WorldVeg project staff, and Research Officers of MOA based at Sigatoka Research Station. The chief guest for the event was the Minister for Education, National Heritage, Culture and Art, Honourable Dr. Mahendra Reddy. Over a thousand participants gathered at the venue and more than 500 packets of Rio Gold seed were distributed with the Research Release sheet containing information on the variety.

ii) Field days in Solomon Islands. The three tomato varieties (Rose’s Choice, MAL Cherry and MAL Fresh) and single sweet pepper (MAL Wonder) variety were officially launched at 3 field days in Honiara (25 February 2015, 8 December 2016, and 23 February 2017) that were jointly organised by WorldVeg and MAL staff. Over 300 seed packets were distributed during the field days. At the first field day, a total of 122 participants attended, during the second and third field days, 30 and 26 farmers and private sector representatives attended. Media were also invited to report on the events in the local newspaper.

Information on improved vegetable production technologies disseminated

Information on improved vegetable technologies is usually disseminated during field days and training organised by the project staff in collaboration with project stakeholders in each country. Training conducted in Fiji and Solomon Islands showed the type of information and technologies promoted for adoption by farmers and agricultural stakeholders.

i) Tomato Grafting Trainings in Solomon Islands

Grafting training at TTM farm in 2014. A total of 30 participants (farmers, RTC staff, and MAL Research Division staff) attended a one-day grafting training Table 7.22) at TTM farm in Honiara on 24 November 2014. Topics covered were (i) introduction to grafting and its importance, (ii) facilities needed for grafting, (iii) preparation of scion and rootstock seedlings, (iv) tomato grafting procedures, (v) management of grafted seedlings, and (vi) grafting with related crop management issues.

Table 7.22: Number of training participants for the tomato grafting training in the Solomon Islands by gender and type

Participants	Total	Gender	
		Female	Male
Farmers	10	1	9
RTC staff	7	5	2
RTC students on internship	3	1	2
NGO staff	4	2	2
MAL Research Division staff	6	3	3
TOTAL	**30**	**12**	**18**

An evaluation conducted at the end of the training indicated that >50% of participants rated the topics and presentations as excellent (Figure 7.15)

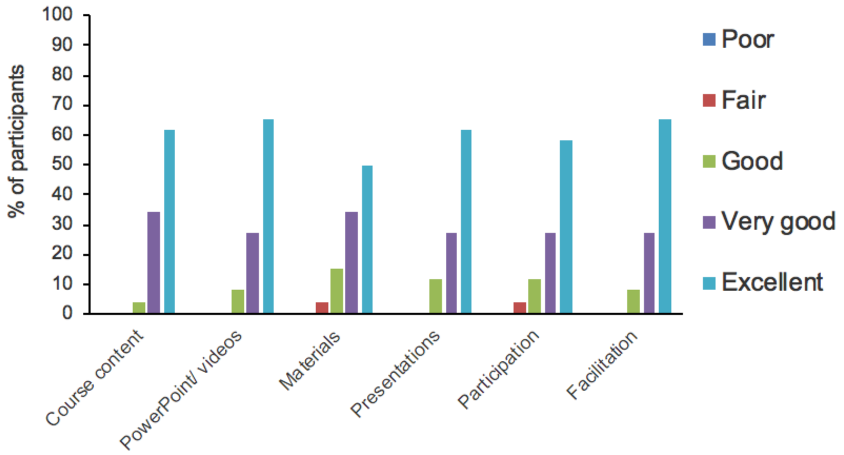

Figure 7.15: Participants' satisfaction on various aspects of the grafting training conducted

The objective of the training was to train participants in grafting techniques and to promote the technology for adoption in the Solomon Islands. Participants noted that they acquired knowledge and skills on tomato grafting from this training (Figure 7.16). Some of the participants pointed out that grafting is a new and worthwhile technology for Solomon Islanders, which will enable the farmers to produce tomato during the rainy season since they are producing for the Honiara market and requested for additional hands-on trainings on grafting.

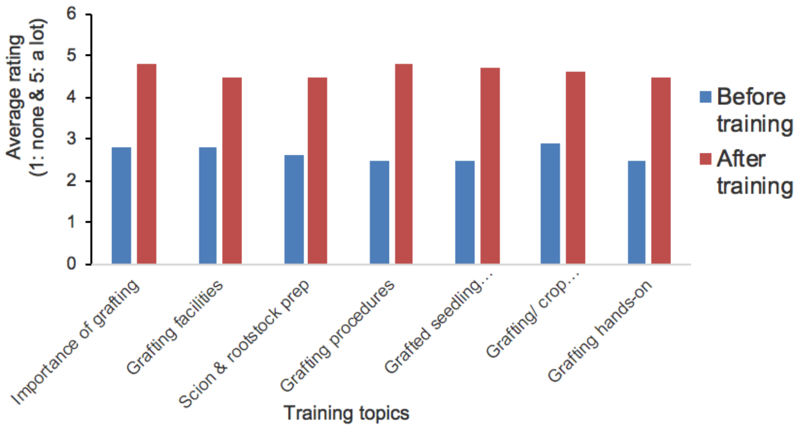

Figure 7.16: Knowledge gain of participants on various grafting topics taught in the training

In March 2015, a total of 238 grafted seedlings were distributed to interested farmers and two RTCs in the east of Honiara. These farmers were participants in a grafting training session conducted by WorldVeg in November 2014. A further 106 grafted seedlings were distributed to the Islanders Grassroot Farmers Association of Burns Creek. Members grew the seedlings alongside non-grafted plants in the field. In mid-May, heavy rain fell continuously for more than three days, causing flooding and waterlogging which caused wilting to non-grafted tomato plants. The grafted plants however, survived the heavy rains and produced good quality fruits (Appendix 13).

Grafting training at Burns Creek and Henderson, Solomon Islands in 2017

Due to high interest in tomato grafting by tomato farmers on the outskirts of Honiara, two hands-on training sessions were conducted at Burns Creek and Henderson on 2nd and 15th of March 2017. At Burns Creek, a total of 20 farmers (12 female and 8 male) attended, while at Henderson, 18 farmers attended (9 female and 9 male). The farmers had hands-on grafting sessions (Figure 7.17) but requested more opportunity to practice. Consequently, they were given a length of grafting tubes and seeds of a flood tolerant eggplant, to enable them to practice grafting.

Figure 7.17. (A) WorldVeg staff trained male farmers on the construction of a grafting healing chamber; (B) Women famers practised grafting

ii) Vegetable and Tomato Production Training in Solomon Islands and Fiji

Vegetable production training in Solomon Islands. A total of 23 participants (students and farmers; 12 female and 11 male) attended a three-day training workshop on vegetable production. The training, jointly organized by TTM and SPC Youth at Work Program, was conducted in Honiara, 7- 9 March 2016. WorldVeg was invited on 9 March, to facilitate the training component on tomato production. Topics covered include (i) raising healthy seedlings, (ii) nursery management (media preparation, seed sowing and pricking), (iii) field preparation and management practices (transplanting, staking, weeding & pruning), and (iv) pests and diseases management.

Tomato production and marketing in Fiji. A total of 29 participants (6 female and 23 male) attended tomato production and marketing training for farmers organized by the Fiji ICM project team (SPC and WorldVeg) in collaboration with MOA, which was held at Sigatoka Research Station on 31 May 2016. Topics covered include growing tomatoes in a business farming system, and tomato production (management and postharvest handling). Figure 7.24 shows participants taking part in a group activity and field visit to plots at Sigatoka Research Station.

Figure 7.18: Participants discussing during a group activity (left) and a field visit to learn about crop management practices (right)

iii) Training on Vegetable GAP and seed/seedling production in Fiji. A total of 34 participants (3 female and 31 male) attended a week-long ToT on GAP and seed/seedling production conducted at the Sigatoka Research Station, Fiji Islands from 10 to 14 March 2014. Evaluation conducted at the end of the workshop indicated that > 50% of participants rated the topics and presentations as excellent. In terms of knowledge acquisition, participants considered that they acquired the anticipated knowledge and skills from the training (Figure 7.19).

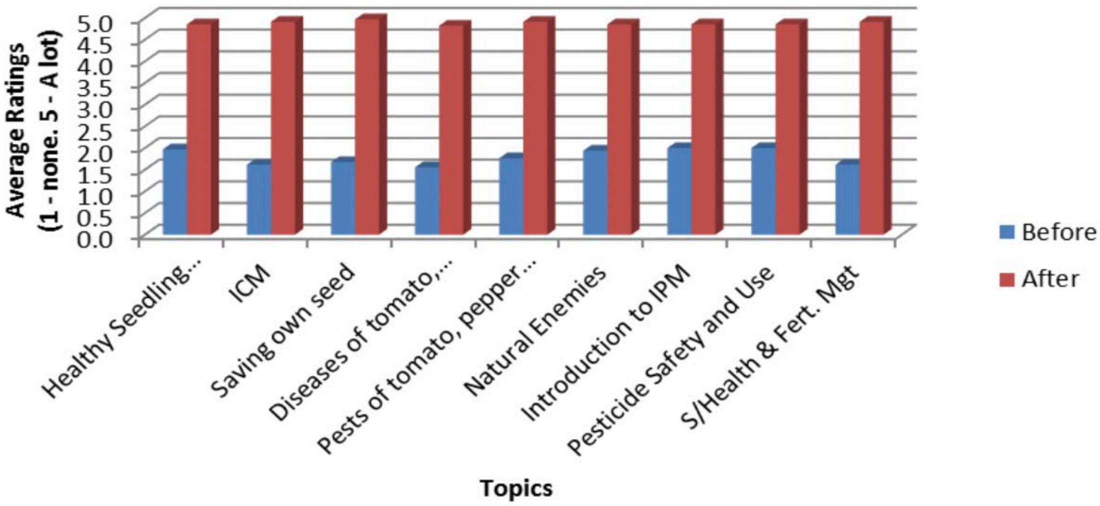

Figure 7.19: Improvement in participants' knowledge of topics covered in the training

One of the goals of the ToT was to prepare participants to teach other farmers in their respective groups about GAP and seed/seedling production. Seventy three percent of the participants felt that the ToT had adequately prepared them to teach farmers in their own communities about GAP and seedling production, while 26% felt that they were still not fully prepared to teach farmers

8 Impacts

8.1 Scientific impacts – now and in 5 years

Now

- **Regional status of diamondback moth resistance to insecticides and development of an insecticide resistance management strategy.** Understanding of the significant threat that resistance to insecticides in diamondback moth poses to sustainable management of the pest. High levels of resistance were measured and documented in Fiji and Tonga. The design and implementation of a regional insecticide resistance management strategy for the pest has been extremely successful and ameliorated the problem posed in Fiji. Such successes are rare.
- **Parasitism of *Crocidolomia pavonana* by *Trichogramma chilonis*.** Genetic and ecological studies of pests and parasitoids in the *Brassica* agro-ecosystem in Samoa showed that parasitism of non-pest host insects that feed on weeds in the system are central to the high levels of parasitism of *C. pavonana* by *T. chilonis* that occur in the crop. Better understanding of this system showed that the non-crop vegetation could be manipulated to improve parasitism rates of the key pest. This improved understanding of the ecological interactions between vegetable pests and natural enemies is relevant this and to other vegetable crop systems.
- **Induction of host plant defences.** Work showed that defences to herbivory in *Brassica* crops (head cabbage (*Brassica oleracea* Capitata) and Chinese cabbage (*B. rapa* Pekiniesis) is highly specific. In response to herbivory (or the application of elicitors of the biochemical responses to herbivory) head cabbage becomes more susceptible to oviposition by diamondback moth, whereas Chinese cabbage becomes less susceptible- the duration of these responses also vary by species, with head cabbage retaining the response for 6 days while Chinese cabbage retains it for only 4 days. The response of head cabbage was manipulated in the field to contrate eggs on plants treated with an elicitor. This exciting development suggests that parts of crops could be temporarily induced to become trap crops (without having to waste resources growing a different plant species to tarp insects), concentrating eggs which could then be destroyed. Research on the responses of natural enemies to herbivore damaged plants showed the importance of associative learning and explains why manipulation of natural enemies at the field scale has to date been so difficult to achieve.
- **FTA ™ cards for pathogen identification.** The development and validation of the FTA™ card protocol as a tool to facilitate collection of pathogen samples for identification has greatly improved capacity to correctly identify the causal pathogens of foliar diseases of tomato and capsicum. This will contribute significantly to improved control of diseases of these crops.
- **Evaluation protocols.** The evaluation protocols developed for tomato, sweet pepper and chili, under this project will be used as reference documents by junior scientists in the Ministries of Agriculture in participating countries. This will increase their knowledge and also enable them to better conduct variety trials whenever a newly introduced crop is brought into the country for evaluation.

In 5 years

- **Regional status of diamondback moth resistance to insecticides and development of an insecticide resistance management strategy.** The strategy has been adopted by cooperating famers. Further work will be required to extend the strategy more widely but its success to date leads us to anticipate that it will be widely adopted within 5 years. This work could serve as a model for other countries, especially those in the region, of how insecticide resistance can be measured, documented and a strategy to combat it formulated using available products that effectively reduce resistance in the pest species and contributes to sustainable ICM.

- **Parasitism of *Crocidolomia pavonana* by *Trichogramma chilonis*.** The improved understanding of the ecology of the system had two important outcomes for longer term improved biological control of *C. pavonana* (and possibly other pests in this and in other crops systems): i) mass rearing and mass releases of *T. chilonis* are not necessary for improved biological control and ii) understanding of the complex ecological interactions in a system can make significant contributions to better pest management. Given the wide adoption of Bt (see below) and improved understanding of this system it is anticipated that sustainable management of *C. pavonana* will be enhanced in 5 years and that lessons will be applied to other pests in other crops.
- **Induction of host plant defences.** It is possible that plant elicitors could be used to improve ICM but manipulating oviposition of pest insects- effectively turning parts of the crop into a trap crop. We will continue to pursue this goal. The work on natural enemy responses has wide scientific impact and implications as it shows how complex the responses of natural enemies are and how much of the work that has been conducted world-wide requires a re-think to achieve field impact.
- **FTA ™ cards for pathogen identification.** Foliar diseases of tomato and capsicum are important production constraints for these crops. The continued use of this technology will allow local scientists to collect the samples required for accurate and identification of diseases and their causal pathogens.
- **Evaluation protocols.** Crop scientists in participating countries will conduct variety evaluation trials with accuracy and efficiency because of their knowledge and skills have been enhanced by their involvement in the variety evaluation protocols developed in the project. As a consequence, new improved varieties introduced will be appropriately evaluated recommendation to farmers.

8.2 Capacity impacts – now and in 5 years

Now

- **Scientific skills of collaborating research staff**. Through true collaboration in research projects, the scientific skills of staff in partner organisations have been enhanced. In particular, the capacity to undertake research on the integrated management of vegetable crops has been built significantly. Collaborating staff have developed capacity in:
    - Evaluation of vegetables for production in the Pacific
    - Measuring the susceptibility of pest insects to insecticides (includes development of bioassay protocols and analysis of data)
    - Developing and implementing an insecticide resistance management strategy
    - Measuring the impact of natural enemies of pest populations so that their utility for inclusion in ICM programmes can be assessed
- **Extension and outreach skills of collaborating extension staff.**
    - The plant health clinic programme has ensured that extension staff have developed their pest and disease diagnostic skills and their skills at engaging with and providing advice to farmers. This was helped enormously by the project's publication of the mobile app "Pacific pests and pathogens" (350 facts sheets on the identification and management of pests and diseases of Pacific crops)
    - Increased capacity to engage deeply with the private sector (eg the relationship between PC staff and AgChem Fiji Ltd to facilitate the importation and marketing of Bt as part of the IRM strategy).

In 5 years

- It is envisaged that the increased capacity that has also been developed through the project's activities will continue. Most of the capacity has been built in ongoing activities (plant health clinics, insecticide resistance monitoring, variety evaluations, development of ICM strategies), this will be consolidated through future ACIAR and other projects in ICM building a solid staff base that will reduce the negative impacts of organisational staff turnover.

8.3 Community impacts – now and in 5 years

Now

- Insecticide Forums conducted in Fiji, Samoa and Tonga increased community awareness of the dangers of pesticides and the necessity to apply them appropriately for personal safety, to reduce impact on the environment and to maintain the usefulness of the pesticides that are used.
- In Solomon Islands, although the project focused on farming communities on the outskirts of Honiara, some of the technologies evaluated under the project were disseminated to Malaita and Western Province. This was made possible through WorldVeg's collaboration with other donor funded projects. For example, in August 2015, a farmer's field day was held for three farming communities in North Malaita in collaboration with WorldFish. Farmers received information and training on vegetable nursery management, tomato and eggplant seed extraction and saving through demonstrations. Seeds of improved varieties of tomato, eggplant and beans have also been distributed to the farmers. Furthermore, in June 2016, three communities in the Western Province received seeds of improved vegetable varieties promoted by the project through collaboration with American Museum of Natural History under their conservation project.

In 5 years

- Farmers in the Solomon Islands have shown interest to adopt grafting for tomato production in the rainy season, and a number of tomato farmers in the outskirts of Honiara have received training on grafting and seeds of the flood tolerant eggplant rootstock variety. Therefore, it is anticipated that tomato production in the rainy season for an increased income will be achieved by the farmers who have received grafting training.
- In Fiji, it is anticipated that farmers receiving training on crop management practices under protective structures will adopt the technology and produce for the local markets in the rainy season.

8.3.1 Economic impacts

Now

- The economic impacts can be realised by an increase in income from growing the high yielding OP varieties of tomato officially released under the project. In the Solomon Islands, Rose's Choice sells for a higher price than local cherry varieties. Furthermore, with the high interest in grafting, if farmers grow grafted tomato plants in the rainy reason, there is an expectation of a higher income from the sale of tomato especially when there is low supply in the local markets. In Fiji, use of protective structures for vegetable production in the rainy season is also a technology that can enable farmers to produce more vegetables for local markets in the off-season. Some farmers in the Sigatoka Valley have received hands on training on crop management practices under protective structures.
- The introduction of Bt has reduced the cost of insecticide inputs for farmers who adopt it as part of a rational IRM strategy. The AgChem Bt costs the same as the cheapest insecticides used before it was introduced, it is approximately 4-5 times cheaper than insecticides such as Indoxacarb and Prevathon, which are routinely

used. The IRM stagey allows effective insect est management within Brassica crops with greatly reduced insecticide input, saving considerable input costs for adopting farmers.

In 5 years

- Farmers in the Solomon Islands have shown interest to adopt grafting for tomato production in the rainy season, and a number of tomato farmers on the outskirts of Honiara have received training on grafting of the flood tolerant eggplant rootstock variety. Therefore, it is anticipated that tomato production in the rainy season for an increased income will be achieved by the farmers who have received grafting training.
- In Fiji, it is anticipated that farmers receiving training on crop management practices under a protective structure will adopt the technology and produce for the local markets in the rainy season.
- Continued savings on insecticide costs will accrue as long as the strategy is adopted.

8.3.2 Social impacts

Now

- Farmers in Fiji and the Solomon Islands now know the difference between hybrid and OP varieties. The release of the OP tomato and sweet pepper varieties, farmers have started saving their own seeds for small scale planting. A farmer on the outskirts of Honiara who has been trained on seed saving under the ICM project been saving his own tomato seeds for planting.
- The plant health clinic program has engendered considerable interest in communities where it has been run. Farmers discuss pest and disease and other agronomic issues at the clinics and leave with advice on crop management.

In 5 years

- Through dissemination of the vegetable production technologies introduced by the project, it is expected that more farmers and households will learn new vegetable production techniques and that they will be interested in establishing their own "*sup sup"* garden (home garden). This may result in improved nutrition and health of families through increased consumption of highly nutritious vegetables. The high rates of non-communicable diseases may also be reduced. The cherry tomato variety officially released in both Fiji and the Solomon Islands has orange flesh and is high in beta carotene. Children especially, will love the colour and its sweet taste.
- Gains ns achieved so far in the clinic program are expected to be consolidated and increased in the coming years as the program expands with additional funding form ACIAR.

8.3.3 Environmental impacts

Now

- ICM technologies such as use of insect exclusion net integrated with Bt has been promoted by the project to reduce the use of broad spectrum insecticides on brassicas. This may reduce negative impacts on natural enemies and the environment.
- The increased use of environmentally safe Bt and the concomitant decrease in the use of broad spectrum insecticides will have obvious environmental impacts and vegetables will be safer for consumers to eat.

In 5 years

- It is expected that the project will have positive environmental impacts through GAP, such as crop diversification and effective management and control of insect pests and diseases. Overall, this will positively contribute to safeguarding environmental and human health. With training in IPM, farmers are now able to differentiate beneficial insects from pests, as well being aware of a wider variety of control options available and can use this information to make informed decisions to minimise pesticide use.
- It is expected that future insecticide use will focus on more bio-rational compounds (eg Bt), resulting in long term benefits and the promotion of biological control based ICM practices that will provide a safer agricultural environment and safer food for consumers.

8.4 Communication and dissemination activities

Project results and outputs were disseminated through:

- Field days to officially release and promote the selected tomato and capsicum varieties adapted to local growing conditions.
- Insecticide forums: community meetings held in Fiji (x3), Samoa and Tonga to explain the mode of action of different insecticides and issues of safety and appropriate application. The insecticide resistance management strategy and information on the effective application of Bt was supplied (in Fijian, Hindi and English) with all sales of AgChem Bt in Fiji.
- Meeting with local journalists facilitate press reports on project activities. Newspaper articles include official variety release events (February 2014, December 2016, and March 2017 in Solomon Islands, and September 2015 & October 2016 in Fiji), grafting training (November 2014) and farmer field day in Malaita (August 2015).
- Presentations were made at international scientific conferences:
    - "Characterisation of *Colletotrichum* populations associated with fruit anthracnose on chili pepper in Fiji" at the 29th International Horticultural Congress, Brisbane, Australia, 17-22 August 2014
    - Atumurirava, F., Nand, N. and Furlong, M. J. (2016). Diamondback moth resistance to insecticides and its management in the Sigatoka Valley, Fiji. In: XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): International Symposium on Horticulture in Developing Countries and World Food Production. *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): International Symposium on Horticulture in Developing Countries and World Food Production*, Brisbane, Australia, (125-130). 17 - 22 August 2014. doi:10.17660/ActaHortic.2016.1128.17
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- The many publications produced during the project are cited below (section 10).

9 Conclusions and recommendations

9.1 Conclusions

The development of high-value crops for domestic consumption and export is a priority for economic development and improved livelihoods in most Pacific Island countries but pests and diseases, and a lack of improved varieties adapted to local growing conditions, remain serious constraints. Vegetable production ranges from relatively sophisticated high input operations through to subsistence farmers who cannot afford expensive inputs and who's technical expertise is sometimes limited. Significant improvements to livelihoods are likely if improved access to appropriate information and inputs can be effected. A focus on basic agronomic practices including improved soil health (possibly utilising legume rotations), judicious selection and use of appropriate selective pesticides and selection of improved varieties of high value vegetables would likely result in significant improvement and contribute to the broader development goal to improve the livelihoods of smallholders and their communities and build and sustain the capacity to develop ICM strategies for high-value crop production.

In a regional project such as this, frequent face to face communication between research partners is essential and to that end the project advisory group (PAG) meetings were invaluable. They brought together the country research and extension teams and fostered a sense of belonging and ownership of joint activities within the project but, more importantly they allowed country partners to identify common problems and work together to solve these. This was particularly evidenced in the approach to the plant health clinics which were eagerly embraced by all countries. All collaborating countries have since changed their agricultural policies to accommodate plant health clinics and include them in the work plans of appropriate extension staff. Despite this, it proved difficult to persuade country collaborators to fully participate in the development of the fact sheets that are the basis for the Pacific pest and pathogens app and which are integral to the future success of the plant health clinic programme. The reasons for this are not immediately clear but when such regional resources are being developed it is important that country counterparts are fully engaged in these activities to ensure that appropriate approaches are taken and, equally importantly, that local capacity is built. The review of PestNet provided important recommendations for the future of the online service, these have for the most part been achieved but the issue of succession planning remains.

In terms of scientific progress, the regional study on diamondback moth resistance to insecticides showed, unsurprisingly, that this issue can be a major problem. The reasons are two-fold- i) excessive use of insecticides contaminates crops and the growing environment, resulting in produce that might be unsafe and environmental contamination and ii) the destruction of natural enemies results in a spiralling use of insecticides to control resistant pests and the emergence of other pest species which are usually suppressed by their natural enemies when pesticide use is not excessive. Before the project was implemented, *Brassica* farmers in Fiji and Tonga, and to a lesser extent in Samoa, resorted to one of the narrow range of broad spectrum insecticides available to them. The introduction of a reliable, cost effective Bt product and its establishment in the marketplace provided a viable option to farmers. The project's partnership with a local retailer, AgChem Fiji, Ltd. was integral to the success of this part of the work as it provided an appropriate distribution channel for the Bt from a source that farmers were familiar with. Despite the success of this initiative, it took a considerable time to get the required permission to import and then sell the Bt- despite its proven safety and prior registration in the country. In the future, where appropriate data are already available, programs to introduce safer, selective insecticides should be expedited so that such delays are avoided and hazardous broad spectrum insecticides can be replaced more quickly. The development of the IRM strategy was also a success but work elsewhere (see Furlong et al., 2013) shows that continuous monitoring and reinforcement of the importance of insecticide rotations is required. Nevertheless, in co-operating farms the strategy demonstrably reduced levels of resistance in DBM to commonly used insecticides and Bt provided a valuable component of the effective but laborious ICM strategy to manage DBM based on placing nets structures over crops in Fiji and Solomon Islands. However, results showed that Bt alone was as effective as Bt and net combinations and it is likely that farmers will use Bt alone.

The work on *T. chilonis* and its parasitism of *C. pavonana* in Samoa took an unexpected turn when the parasitoid's capacity to attack eggs of other Lepidoptera in the *Brassica* crop environment was investigated. It was shown that the parasitoid's catholic taste was an advantage in the biological control of *C. pavonana* as parasitoid numbers could build up on eggs of an endemic moth that oviposited on an invasive weed. This resulted in a "spill over" of *T. chilonis* to attack *C. pavonana* eggs in *Brassica* fields. Thus, manipulation of alternative hosts and their host plants rather than the costly, labour intensive mass rearing and release of parasitoids is likely to be effective- we were able to demonstrate this experimentally. Similarly, host plant manipulation with elicitors of plant responses to diseases and pest feeding proved effective. In the case of responses to herbivory, the increased oviposition that could be achieved on treated plants has the possibility to improve trap cropping and attract natural enemies to high densities of pests in the field. This should be explored further.

The development of a variety evaluation protocol for tomato, sweet pepper and chili is an important step as it provides a guide for staff in partner countries to continue with variety evaluation. In most countries, off-season vegetable production is difficult and the evaluation of protected cropping structures and tomato grafting are promising and should be promoted. Grafting is a simple technology and has been successfully tested in the Solomon Islands both on-station and on-farm. Farmers are keen on the technology but the availability of grafting tubes is a constraint which needs to be addressed if this technology is to be adopted. Extension activities, like field days, are effective for information dissemination and promotion of improved vegetable production but in the future plant health clinics are likely to be the most effective method of providing farmers with the information that they need to grow their high value crops sustainably.

9.2 Recommendations

- The plant health clinics have been a great success and the ministries in all collaborating countries are keen for them to become part of their ongoing extension efforts. This is important and a coordinated training program for plant doctors should be complemented by a thorough planning program in each ministry where resources that are committed to the program are clearly defined. Extension officers that are trained must be given ongoing opportunity to use their newly acquired skills if the programmes are to succeed.
- The successful impart and marketing of Bt shows that newer, selective insecticides can be used effectively in the region. Other selective insecticides, that are compatible with IPM should be identified and imported. Whenever new products are introduced to the market they should be accompanied by information on effective use and strategies to avoid the development of resistance in target pests.
- Biological control is the foundation of successful IPM strategies but many current practices serve to disrupt or even destroy critical biological control agents. Researchers and extension officers need to be educated in the importance of natural biological control and how beneficial arthropods can be integrated into economically viable and effective pest management programmes.
- Evaluation of OP tomato and capsicum varieties (which allow farmers to save their own seed) was completed successfully and the best performing adapted varieties were officially released and promoted. To ensure sustainability, farmers need training on the management of seed production plots, seed saving techniques, and the processes of seed extraction and storage. This will ensure that the common practices

of most farmers such as selling of the best fruits in local markets and collecting fruits of low quality to save seeds for next round of planting are avoided.

- There is a renewed interest in OP seeds in the Pacific region (discussed at a Pacific Open Pollinated Seed Roundtable meeting organised by Pacific Island Farmer Network (PIFON) in Honiara, November 2016). Therefore, the research efforts and successes of the ICM project in identifying OP tomato and capsicum varieties adapted to the growing conditions in the region must be further extended by establishing a seed system for OP varieties, starting at national level and later at the regional level. This will enable other Pacific countries interested in utilising the tomato varieties released through the ICM project, to access seeds. For instance, farmer representatives from Papua New Guinea, Samoa and Vanuatu who attended the OP Seed meeting enquired about how they could access seeds of the OP tomato varieties officially released in Fiji and the Solomon Islands.
- Results of the DNA samples extracted from tomato and chili pepper foliar diseases sent on FTA™ cards to WorldVeg HQ for identification confirmed the presence of several important foliar diseases on the two crops in Fiji and the Solomon Islands. Although the survey was limited in the number of samples to be fully representative, the study suggests that pepper *Cercospora* leaf spot caused by *C. capsici*, tomato leaf spot caused by *Pa. fulva*, and tomato black mold caused by *Ph. destructiva* are the main diseases of concern. Based on the results, there is a need to continue with this work to accurately identify pathogens. There remains an existing gap in the development of an Integrated Pest and Disease Management package for tomato and capsicum, especially the newly introduced varieties officially released in Fiji and the Solomon Islands.
- Vegetable production during the rainy season is an ongoing issue faced by most smallholder farmers in the Pacific. Protected cropping and grafting might provide the technologies required to extend the growing seasons of these crops.
- The soil health survey conducted at ICM project sites in Fiji showed that soil organic matter (SOM) or total carbon in soils was low at most locations. SOM is derived from decomposed residues of plants and animals, therefore, it is important to complete the long-term soil health trial initiated during the project
- Most junior scientists in the region lack knowledge and skills in data handling and statistical analysis. Such skills shul deb better embedded in local university curricula.

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11 Appendixes

11.1 Appendix 1: Pest sampling sheets and Excel Decision spread sheet to determine if combined pest threshold is exceeded in Brassica crops

In the Pacific Islands, the diamondback moth (DBM: *Plutella xylostella*) large cabbage moth (LCM; *Crocidolomia pavonana*) are the predominant pests of *Brassica* crops and they often co-occur. A sampling protocol was developed to integrate DBM densities and the proportion of plants infested by LCM, so that growers could make an informed decision about treating their crops with Bt. The strategy used a dynamic threshold for DBM densities that changed with the age of the crop. Thresholds were moderate when plants were first transplanted to the field, very low when plants were at the most susceptible “cupping” stage and high post heading, when very high densities of DBM (which do not feed the heads of plants at this stage. LCM threshold could be changed to allow greater or lower tolerance of this pest. The strategy was tested against conventional farmer practice in Fiji and Samoa (Furlong, 2016).
Methods

1. 30 plants within a crop were sampled at least two times per week for the entire crop cycle (Figure 1)
2. Data were immediately entered into a spread sheet to determine if the DBM threshold, the LCM threshold or the combined pest threshold for the crop at that stage of development had been exceeded (Figure 2).
3. If the threshold exceed application of Bt was made.
4. Three to four days later the crop was sampled again, the data recorded and then entered into the spread sheet and it was determined if the threshold had been exceeded. This process was continued, with applications of Bt as necessary, until two weeks before harvest.
5. Note: if LCM egg densities were high, more regular sampling was recommended. Bt applications were not recommended based on egg densities as- i) LCM egg mortality is typically high in the field and ii) Bt is not effective against eggs but it is very effective against neonate larvae and the sampling methods improved timing of applications.

SITE: Nu'u

	DBM						LCM					
Plant #	**Eggs**	**I**	**II**	**III**	**IV**	**P**	**Egg mass**	**Small larvae**	**Large larvae**	**P**	**Predators/ parasites**	**Other pests**
1	0	0	0	0	0	0	0	20	0	0	0	0
2	0	0	0	0	0	0	0	7	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	0	1	0	0	0	0	0	0	hellula
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	20	0	0	0	0
7	0	0	0	3	0	1	0	30	0	0	spider	hellula
8	0	0	0	0	0	0	3	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	2	0	0	0	0	0	hellula
11	0	1	0	0	0	0	1	0	0	0	ants	whiteflies
12	0	0	0	0	0	0	2	0	0	0	0	0
13	0	0	0	1	0	0	0	0	0	0	ants	0
14	0	0	0	0	0	0	2	19	0	0	0	0
15	0	0	0	0	0	1	1	0	0	0	ants	whiteflies
16	0	0	0	0	1	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	5	0	0	0	0
18	0	0	0	0	0	0	2	13	0	0	spider	hellula
19	0	1	0	0	0	0	1	0	0	0	0	0
20	0	0	0	0	0	0	2	12	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	2	4	0	0	litura
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	1	0	0	24	0	0	0	0
26	0	0	3	0	0	0	3	0	0	0	ants	litura
27	0	0	0	0	0	0	0	0	1	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	1	0	0	0	0	ants	0
30	0	0	1	3	0	0	0	14	7	0	0	0
		4	4	7	3	5	17	166	12			

Date: 01/12/2015

Crop: head cabbage

Site: 6 weeks

Weather: fine

Pesticide applied: nil

	DBM						LCM					
Plant #	**Eggs**	**I**	**II**	**III**	**IV**	**P**	**Egg mass**	**Small larvae**	**Large larvae**	**P**	**Predators/ parasites**	**Other pests**
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	1	0	2	0	0	0
3	0	0	2	0	0	0	0	30	0	0	0	0
4	0	0	0	0	0	0	0	25	0	0	0	0
5	0	0	0	1	0	0	1	58	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0
7	0	1	0	0	0	0	0	28	0	0	0	0
8	0	0	1	0	0	0	0	0	8	0	0	0
9	0	0	0	0	1	0	1	0	0	0	0	0
10	0	0	0	0	0	1	0	30	0	0	0	0
11	0	0	0	0	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	1	0	0	0	0	0	39	0	spider	0
14	0	0	1	0	0	0	2	2	0	0	0	0
15	0	0	0	0	0	0	0	16	0	0	0	0
16	0	0	0	0	0	0	1	16	15	0	0	0
17	0	0	0	0	0	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	1	0	0	0	0
20	0	0	0	0	0	0	0	0	8	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	2	0	0	0	0	0
23	0	0	0	0	0	0	0	0	20	0	0	0
24	0	0	0	0	0	0	1	0	0	0	0	0
25	0	0	1	0	0	0	0	0	1	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	8	0	0	0
28	0	0	0	0	0	0	0	20	2	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
		1	6	1	2	2	11	226	103			

Date: 04/12/208

Crop: head cabbage

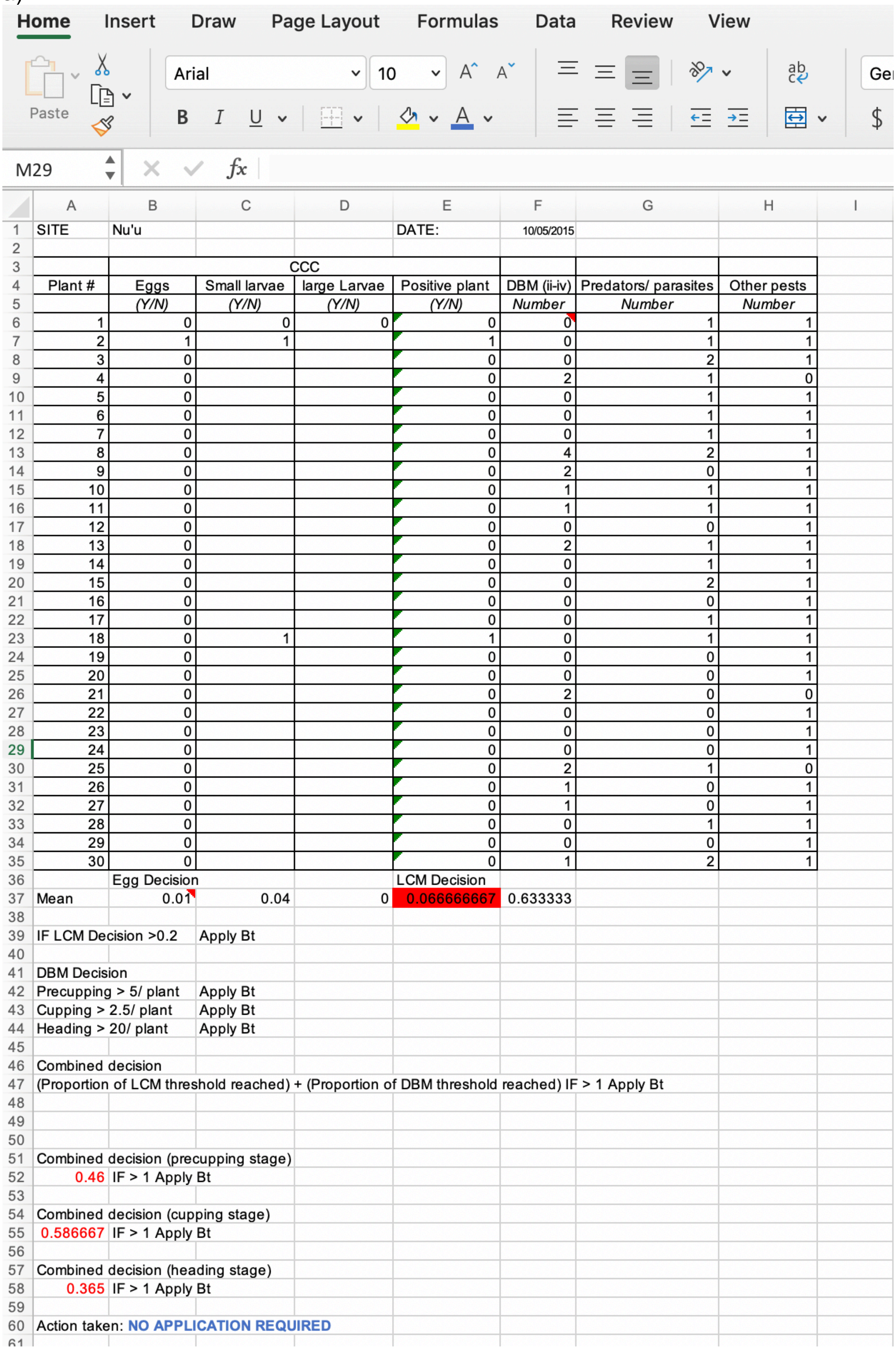
Site: 6 weeks

Weather: very hot

Pesticide applied: nil

Figure 1: sample sheets showing successive sampling data in a head cabbage crop at Nu'u Samoa during a crop-long sampling exercise to test the threshold strategy.

a)



SITE	Nu'u			DATE:	10/05/2015		
	CCC						
Plant #	Eggs	Small larvae	large Larvae	Positive plant	DBM (ii-iv)	Predators/ parasites	Other pests
	(Y/N)	*(Y/N)*	*(Y/N)*	*(Y/N)*	*Number*	*Number*	*Number*
1	0	0	0	0	0	1	1
2	1	1		1	0	1	1
3	0			0	0	2	1
4	0			0	2	1	0
5	0			0	0	1	1
6	0			0	0	1	1
7	0			0	0	1	1
8	0			0	4	2	1
9	0			0	2	0	1
10	0			0	1	1	1
11	0			0	1	1	1
12	0			0	0	0	1
13	0			0	2	1	1
14	0			0	0	1	1
15	0			0	0	2	1
16	0			0	0	0	1
17	0			0	0	1	1
18	0	1		1	0	1	1
19	0			0	0	0	1
20	0			0	0	0	1
21	0			0	2	0	0
22	0			0	0	0	1
23	0			0	0	0	1
24	0			0	0	0	1
25	0			0	2	1	0
26	0			0	1	0	1
27	0			0	1	0	1
28	0			0	0	1	1
29	0			0	0	0	1
30	0			0	1	2	1
	Egg Decision			LCM Decision			
Mean	0.01	0.04	0	0.066666667	0.633333		

IF LCM Decision >0.2 Apply Bt

DBM Decision
Precupping > 5/ plant Apply Bt
Cupping > 2.5/ plant Apply Bt
Heading > 20/ plant Apply Bt

Combined decision
(Proportion of LCM threshold reached) + (Proportion of DBM threshold reached) IF > 1 Apply Bt

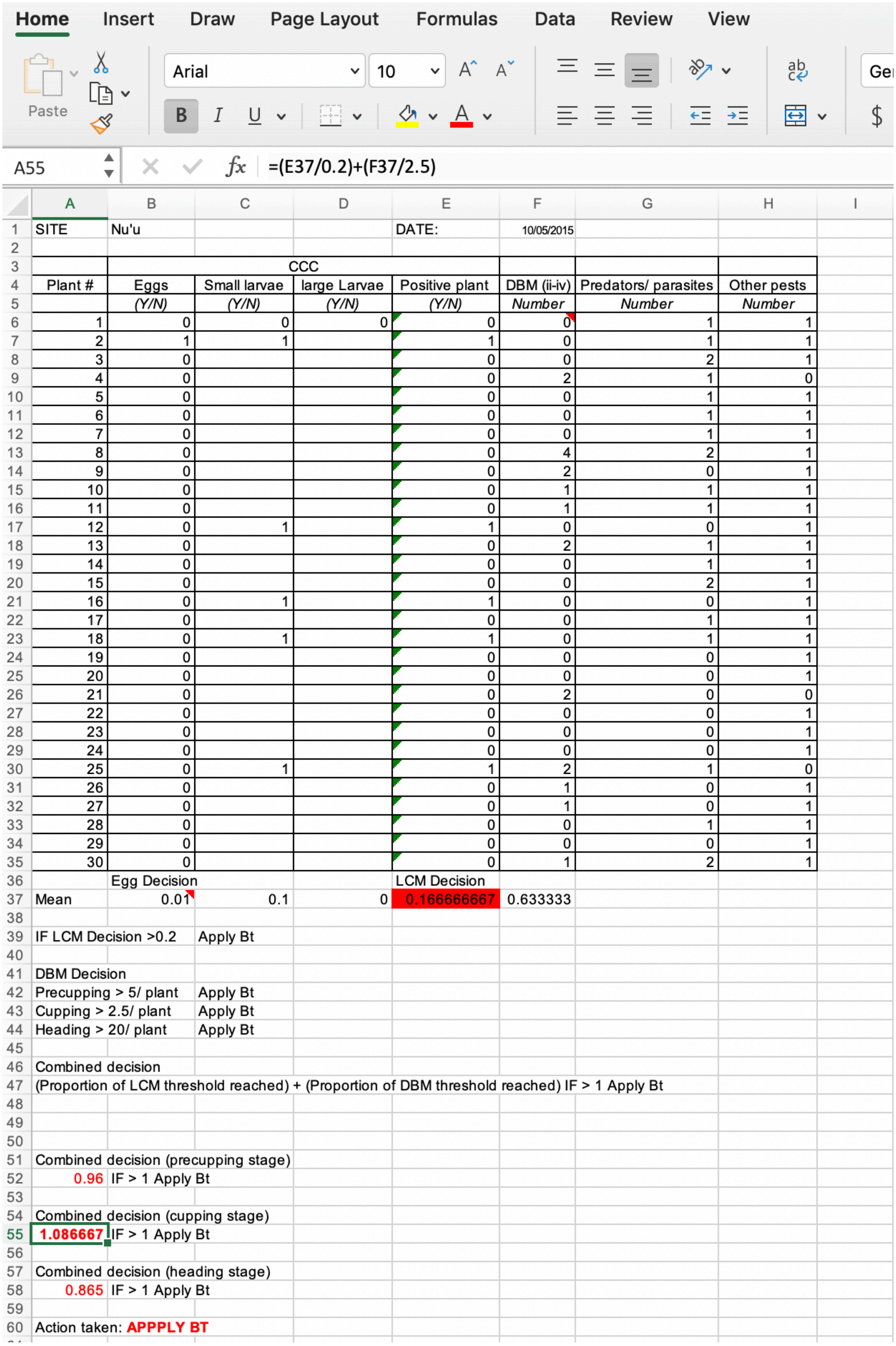
Combined decision (precupping stage)
0.46 IF > 1 Apply Bt

Combined decision (cupping stage)
0.586667 IF > 1 Apply Bt

Combined decision (heading stage)
0.365 IF > 1 Apply Bt

Action taken: **NO APPLICATION REQUIRED**

b)



	A	B	C	D	E	F	G	H
1	SITE	Nu'u			DATE:	10/05/2015		
2								
3			CCC					
4	Plant #	Eggs	Small larvae	large Larvae	Positive plant	DBM (ii-iv)	Predators/ parasites	Other pests
5		*(Y/N)*	*(Y/N)*	*(Y/N)*	*(Y/N)*	*Number*	*Number*	*Number*
6	1	0	0	0	0	0	1	1
7	2	1	1		1	0	1	1
8	3	0			0	0	2	1
9	4	0			0	2	1	0
10	5	0			0	0	1	1
11	6	0			0	0	1	1
12	7	0			0	0	1	1
13	8	0			0	4	2	1
14	9	0			0	2	0	1
15	10	0			0	1	1	1
16	11	0			0	1	1	1
17	12	0	1		1	0	0	1
18	13	0			0	2	1	1
19	14	0			0	0	1	1
20	15	0			0	0	2	1
21	16	0	1		1	0	0	1
22	17	0			0	0	1	1
23	18	0	1		1	0	1	1
24	19	0			0	0	0	1
25	20	0			0	0	0	1
26	21	0			0	2	0	0
27	22	0			0	0	0	1
28	23	0			0	0	0	1
29	24	0			0	0	0	1
30	25	0	1		1	2	1	0
31	26	0			0	1	0	1
32	27	0			0	1	0	1
33	28	0			0	0	1	1
34	29	0			0	0	0	1
35	30	0			0	1	2	1
36		Egg Decision			LCM Decision			
37	Mean	0.01	0.1	0	0.166666667	0.633333		
38								
39	IF LCM Decision >0.2		Apply Bt					
40								
41	DBM Decision							
42	Precupping > 5/ plant		Apply Bt					
43	Cupping > 2.5/ plant		Apply Bt					
44	Heading > 20/ plant		Apply Bt					
45								
46	Combined decision							
47	(Proportion of LCM threshold reached) + (Proportion of DBM threshold reached) IF > 1 Apply Bt							
48								
49								
50								
51	Combined decision (precupping stage)							
52	0.96	IF > 1 Apply Bt						
53								
54	Combined decision (cupping stage)							
55	**1.086667**	IF > 1 Apply Bt						
56								
57	Combined decision (heading stage)							
58	0.865	IF > 1 Apply Bt						
59								
60	Action taken: **APPPLY BT**							

Figure **2 a)** Completed excel decision sheet indicating that based on sample data, decision should be **not to apply Bt** as the combined DBM/ LCM threshold was not exceeded for the crop stage (cupping). **b)** Completed excel decision sheet indicating that based on sample data, decision should be **to apply Bt** as the combined DBM/ LCM threshold was exceeded for the crop stage (cupping)

11.2 Appendix 2: Protocols for Activities 2.4b and 2.5 (trials conducted in Fiji and the Solomon Islands.

Dr. Rishi Burlakoti, Plant Pathology, AVRDC, HQ

<u>Objective 2.4b: Evaluate biochemical elicitors of pathogen resistance</u>
Summary of previous work At AVRDC-HQ (detailed in annual reports 2014 and 2015): Efficacy of 5 plant activators, (i) NPA (Neutralized phosphoric acid), (ii) BION™ (Acibenzolar-S-methyl), (iii) ReZist™ (iv) Potassium silicate, and (v) Chitosan, were evaluated during 2013 and 2014 in AVRDC's greenhouse. These products were also evaluated in field trials in 2011. The efficacy of these products was evaluated to control 4 tomato diseases (late blight, early blight, bacterial spot, and southern blight) and 3 pepper diseases (Phytophthora blight, southern blight, and bacterial spot). Results showed that NPA, BION™, and ReZist™ showed broad-spectrum of resistance for multiple diseases of tomatoes and paper. The detailed results are provided in Table 1.

Table 1. Efficacy of plant activators in suppressing diseases of pepper and tomato in glasshouse trials, AVRDC Taiwan, 2013 and 2014

Disease	Effect of activator on disease severity[1]				
	NPA[2]	BION™	ReZist™	Potassium silicate	Chitosan
Tomato late blight	+	+	+	-	-
Tomato early blight	-	-	+	-	-
Tomato bacterial spot	+	+	-	-	-
Pepper bacterial spot	-	+	-	-	+
Pepper Phytophthora blight	+	+	+	-	-
Tomato southern blight	+	+	+	-	-
Pepper southern blight	+	-	+	+	+

- [1]+ = Significant reduction in symptom severity, - = no significant reduction in disease severity
- [2]Neutralized phosphorous acid

Table 2. Dose, active ingredient, and potential mechanism of the plant defense activators evaluated in the trials

Activator	Active ingredient	Potential mechanism
NPS (1000 ppm)	K_2PO_3	SAR / growth suppression
BION™ (100 ppm)	Acibenzolar-S-methyl	SAR
ReZist™ (5000 ppm)	Chelated copper, manganese, and zinc	SAR / growth suppression
互力健 (500 ppm)	chitosan	SAR / growth suppression
potassium silicate (600 ppm)	K_2SiO_3	SAR / growth suppression

Objective 2.4b: 2016 Field Trial Design for Fiji and Solomon Island

Target Diseases:
Tomatoes- Leaf mold, gray leaf spot and target spot
Bell pepper- Southern blight (*Sclerotiorum rolfisii*)

Treatment compared in field trials: (i) Anti-Rot (Phosphoric acid) (ii) Standard (commonly used) fungicides to control target diseases (iii) Anti-Rot + standard fungicides (iv) Control

(Note: If BION™ and ReZist™ are commercially available in the country, theycan be included in the field trials.**)**

Cultivars: Cultivars of tomatoes and peppers susceptible to target diseases. Better to include moderately resistant or resistant cultivars if available

Experimental design:

- Separate field trials set for each crop
- Factorial RCBD (randomized complete block design) if more than 1 cultivars is used. For example: if 2 cultivars and 4 treatments (2 x 4 = 8) treatments in factorial arrangement
- RCBD is fine if only one cultivar is used in field trial
- Replication: 4, 20 plants per replicate
- Plant space 40cm, plot size: 1.5 m x 4 m
- Boarder: 1.5m spacing surround each plot
- Use highly susceptible cultivars in all boarders with no fungicide to increase the disease pressure in the field
- Choose the trial sites, with history of targeted diseases.

Example of 2 x 4 factorial RCBD Design

2	1	4	3	4	3	2	1	
B	A	A	B	A	B	B	A	Rep 1

3	1	4	2	3	4	2	1	
A	B	A	B	B	A	A	B	Rep 2

1	2	4	3	1	4	3	2	
A	B	B	A	B	A	A	B	Rep 3

4	2	3	1	2	3	4	1	
A	B	A	B	A	A	B	B	Rep 4

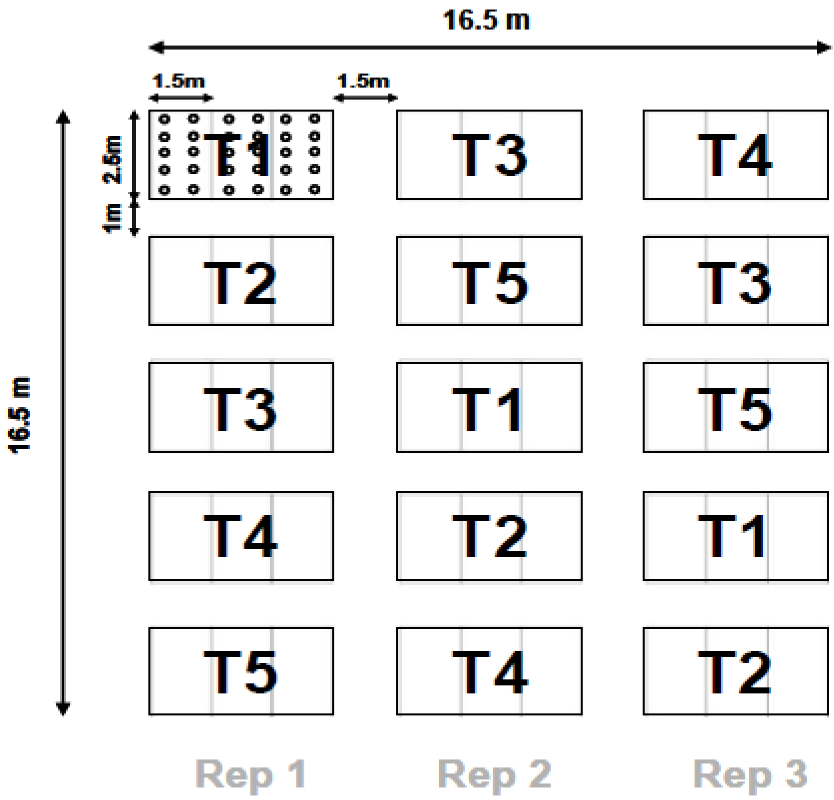
Two factors: 1. Spray treatment (Trt 1, 2,3, and 4). **2.** Variety (A and B)

Example of Simple RCBD trial (from trail conducted in Inonesia)

1. Seeding: Tomato variety= Marta. Seed grown in plastic trays; medium sterilized soil and manure (1:1). Seedlings was covered by insect netting.

2. Land preparation and transplanting: Experimental design based on the AVRDC recommendation, the plot was made and use much for control the weed. Manure and the standard fertilizer were added before mulching. The land preparation was conducted January 13th -15th 2013. After 4 weeks of seedling the transplanting was done in January 20th, 2013.

3. Maintenance:
a. Addition of fertilizer: Fertilizer (2 gL^{-1} (Cristalon (N= 16%, P= 16%, K= 16%) applied 6, 13, 20, 27 of February 2013, with dose.
b. The bamboo stick (2m) was used to stake plants on 31 January 2013.
c. Application of treatments: Treatments was done a week after transplanting on 27 January 2013.



Treatment 1*:* Spray NPS (1000 ppm) every week after transplanting.
Treatment 2: No treatment control.
Treatment 3: Spray Foli-R-Fos 400 SL (5300 ppm) every week after transplanting.
Treatment 4: Spray Daconil 75% WP (1667 ppm) and Acrobat 50 % (250 ppm) WP with farmer practice. The farmer used a mixture of daconil and acrobat, usually applied every 3 days in the morning; if there was rain overnight this was applied the following morning.
Treatment 5: Spray Daconil dan Acrobat 50 % WP with farmer practice and instead of spraying Foli-R-Fos 400 SL 2 weeks before harvesting. The farmer used a mixture of daconil and acrobat, usually applied every 3 days in the morning; if there was rain overnight this was applied the following morning.

4. Observations

- The first observation was done in 3 of March 2013. The incident and severity of disease were calculated, however the data still on process. Base on the data we can see the treatment is comparable. The NPS, Foli-R-Fos 400 SL, and farmer's practice treatments have been infected by LB but very low, however control (without treatment) was infected LB very high (Fig. 9-11).

- Disease severity rating: Disease severity should be rated with a one-week-interval since the first symptom show up until the end of the experiment.
  0 = no symptoms
  1 = 1-5% leaf area affected, small leaf lesions, and no stem lesion,
  2 = 6-15% leaf area affected, necrosis-restricted leaf lesions, and no stem lesion,
  3 =16-30% leaf area affected, coalescent leaf lesions, and/or tiny water-soaked stem lesions,
  4 = 31-60% of leaf area affected, edge-expanding leaf lesions, and/or a few small stem lesions,
  5 = 61-90% of leaf area affected, drying leaf lesions, and/or edge-expanding stem lesions,
  6 = 91-100% of leaf area affected, leaves blighting, extensive stem damage, and/or plant dead

- Yield Assessment:
  Cumulated yield (total and marketable grade) should be calculated until the end of the experiment.

Activity 2.5. Develop improved techniques for disease diagnosis and monitoring in targeted vegetable crops

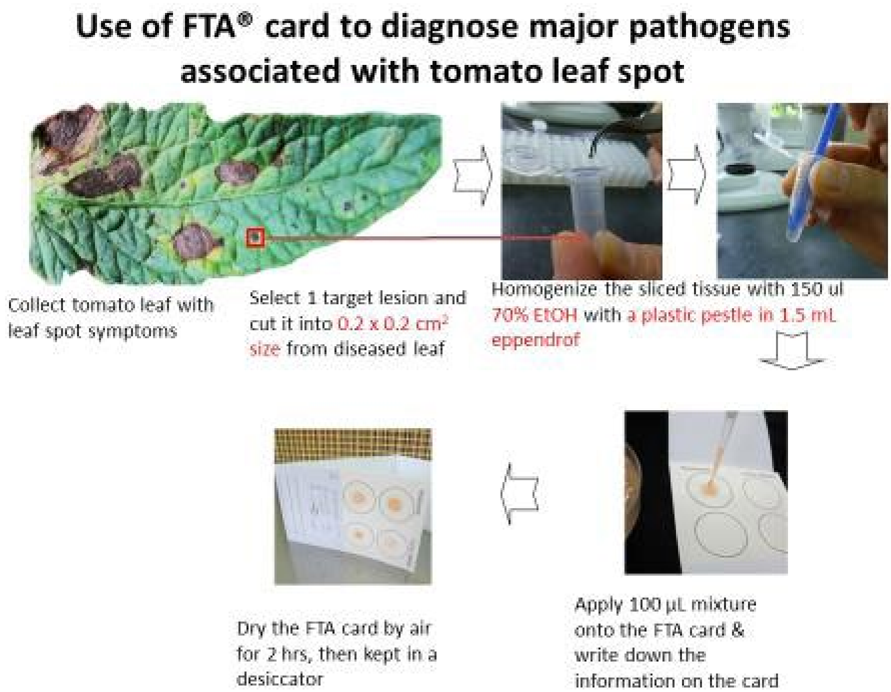
Tomato foliar diseases samples were collected from several locations in Taiwan. The molecular assay (FTA™ cards) were validated to diagnose foliar diseases of tomatoes. The molecular diagnosis technique (FTA™ cards) were successful to identify following diseases of tomatoes: (i) early blight (*Alternaria solani*), (ii) Target spot (*Corynespora cassiicola*), (iii) grey leaf spot (*Stemphyllium* spp.), and (iv) bacterial spot (*Xanthomonas* spp.).

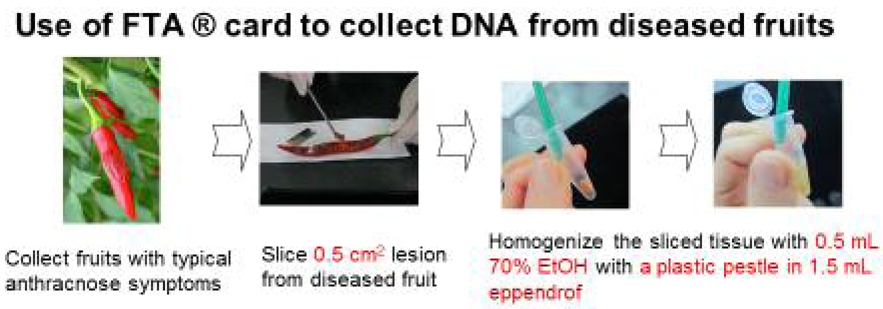
These techniques are available to identify these foliar diseases of tomatoes as well as pepper diseases including foliar diseases and anthracnose from target countries listed in the project.

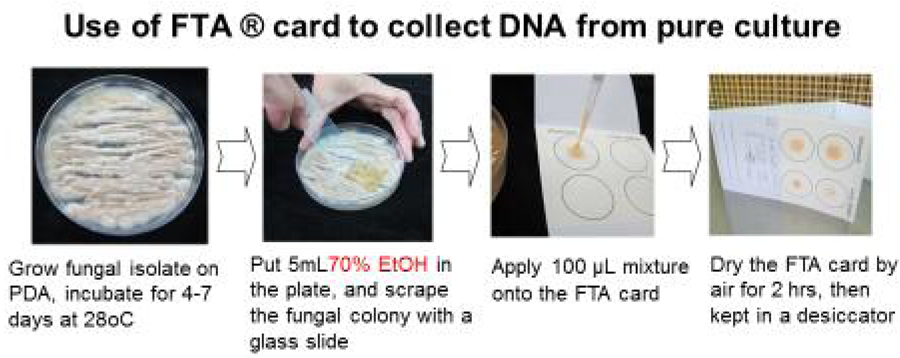
Collecting DNA from necrotic spots on tomato leaf

1. Conduct field survey using a stratified-systemic sampling to determine the leaf spot incidence of the field.
2. Based on visual symptoms, classify the lesion type found in the field.
3. Collect four tomato leaves with the targeted lesion type. Get each of them from different sites in the field as you can.
4. From each leaf, one lesion was cut into a small piece of ca. 0.1 X 0.2 cm2 in size. (Avoid using over decayed or coalesced lesions). Do not use larger piece of the sample. While cutting tissue, also cut little bit healthy portion along with infected portion (See the picture below)
5. Transfer the tissue piece into a 1.5mL microcentrifuge tube with 150 uL 70% ethanol to submerge the tissue.
6. Grind the tissue with a disposable plastic pestle fitted 1.5 mL microcentrifuge tubes.
7. Fold back the cover of one FTA® card and apply one drop (ca. 100uL) of the plant homogenates onto one application area of the card
8. Repeat step 5-8 to collect other three samples for the lesion type. Use one FTA cards to collect 4 samples for each lesion type.
9. Write down the number/code of disease sample in the appropriate “Sample ID” box on the cover of the FTA® card.
10. Unfold the cover and allow the card to dry at room temperature for 2 hrs.
11. Once dry, store the cards in a foil bag and keep in a desiccator at room temperature before shipping to AVRDC.

Prepare a list of FTA cards samples with background information including host/variety, date collected, location (GPS data), leaf spot incidence; symptom description; collector and field descriptions etc.







Activity 2.5: Protocols for conducting field disease survey

Survey protocol and sampling method for tomato diseases in the field

A recommended survey protocol for tomato diseases is as follows:

1. Select the survey sites. A complete disease survey should contain the target sites with various geographic places, altitudes, and farming system etc. According to time and resources, three to five fields per target site are recommended to be surveyed. Please create a simple map showing the field location in the target site of the area.

2. Prepare the data collect sheets (See appendix 1).

3. Make a brief overview at the beginning in each field. Note the crop variety and planting date, the field layout with estimated total plant population, and if possible the disease distribution (e.g. aggregated/patchy or uniform/random).

4. Decide on the sampling method. Ideally, a total of 150-200 plants will be assessed for disease symptoms presence and severity in each field in order to provide a measure of the incidence of disease symptoms.

   i) Stratified-systemic sampling method

   For tomato, a stratified-systematic sampling method is suggested.

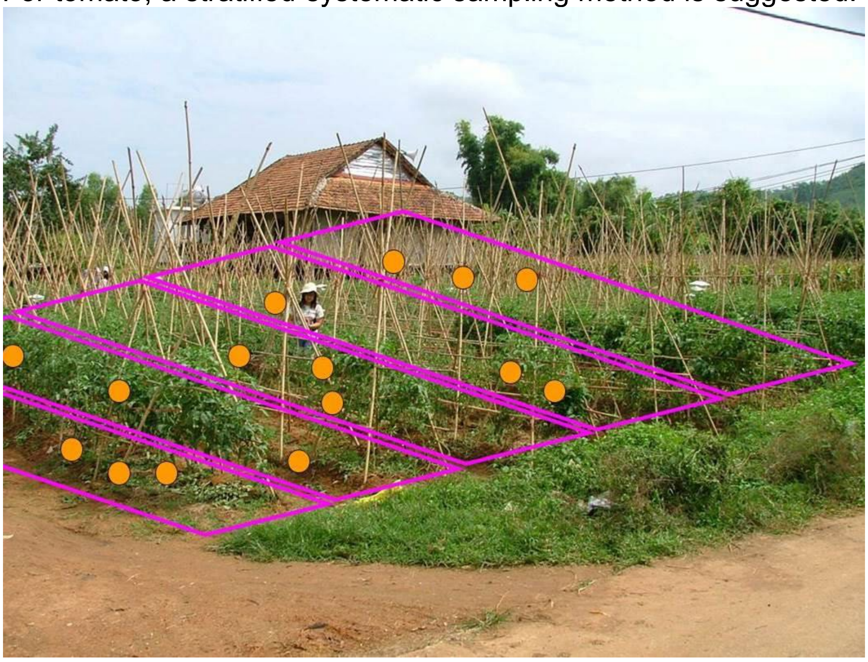


Fig 1. Sampling field of plot-stratified.

The estimated total plant number in the field works out what sampling frequency you need to use to obtain an even coverage across the whole field (e.g. in Fig.2. the field is composed of 6 plots each of about 100 plants, and in order to assess 150 plants you need to sample 25 plants evenly spaced across each plot = every 4th plant should be assessed)

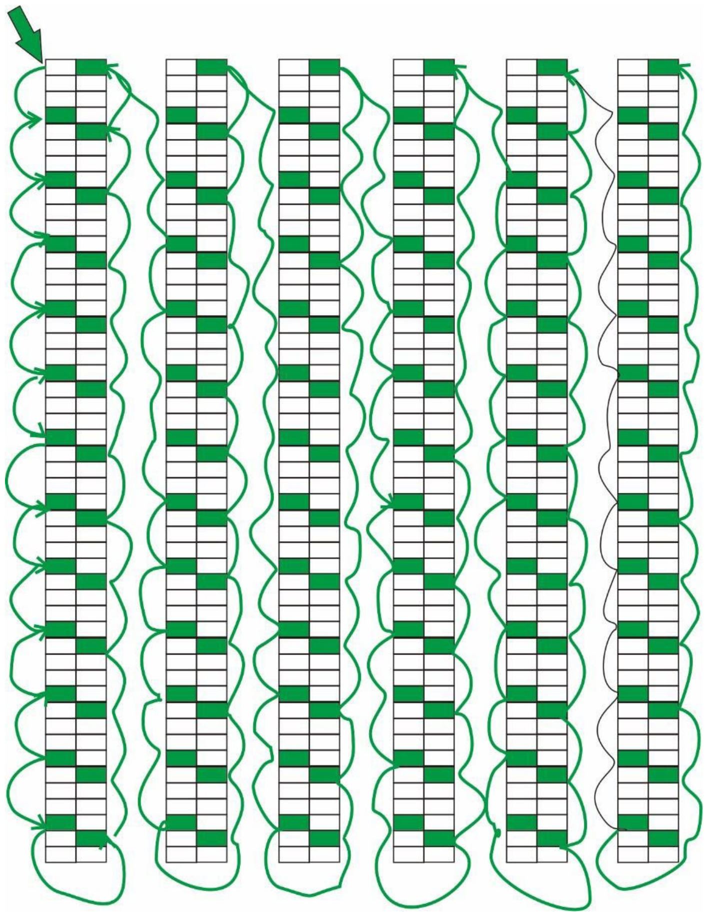


Fig. 2. Stratified-systemic sampling for disease assessment (e.g. tomato). First, systematic strata: evenly assess 150 from 6 plots = 25 plants per plot. Then, secondary systematic strata: 25 of 100 plants in the plot should be sampled at a systematic interval = assess every 4th plant).

Note: Stratified-systemic sampling method is the best method for disease surveys of soil-borne diseases. However, this method is labor-intensive and requires more. If the numbers of survey sites are small, this method can be used. However, if the number of survey sites is high, alternative methods such as random sampling methods can be used.

ii) Random sampling methods.

Random sampling methods, such as sampling using M, Z, W or X patterns can be followed. The sample numbers can vary based on field sizes. In general sampling in 10-15 different spots in one field is acceptable. You can make 2 x 1 m^2 string and observe the numbers of plants within that plot to record the disease incidence and severity of tomato plants. Please see the illustrated picture of random sampling methods for disease survey. These methods are also widely accepted for plant disease surveys.

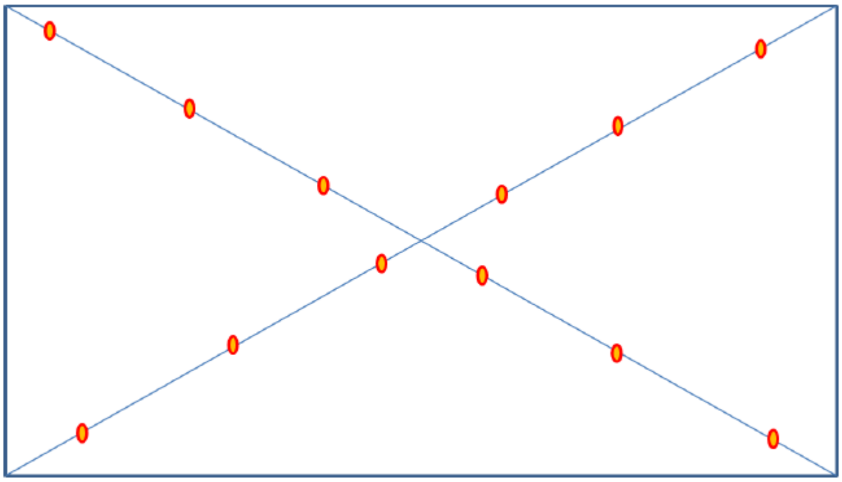


Fig. 3. An example of random sampling method using X-pattern in field

iii) Take samples for further identification. Take a photograph of each sample before you take it from the plant.

   a) For fungal and bacterial diseases: for symptoms you are unsure of the cause, or diseases you wish to isolate and maintain in your lab, collect samples from 3 separate plants per field.
   b) For virus-like symptoms: separately collect leaf samples from 3-6 plants per field (chose the youngest leaves with symptoms, dry the samples with silica gel or calcium chloride.

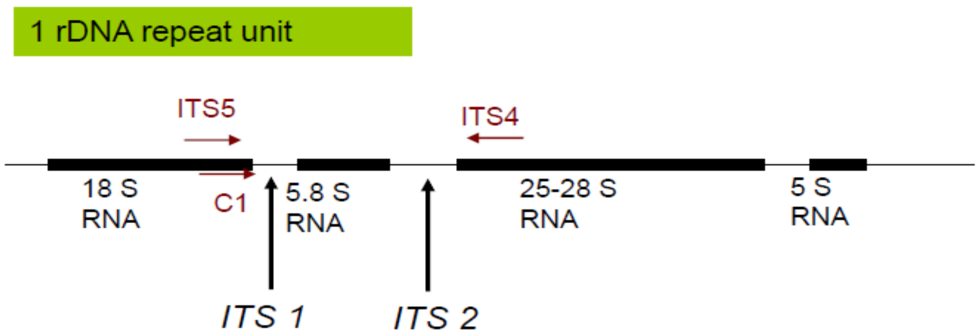
iv) Identify pathogen by morphology or molecular assay. Samples collected from the field can by examined under a microscope. Pathogens, or sometimes saprophytes, might be observed. Therefore, a pathogenicity test of the collected isolates is necessary for the pathogen identification.

11.3 Appendix 3: FTA Card-based Protocol for PPAN

Evaluation and establishment of FTA card-based Protocols to identify *Colletotrichum* species casing pepper anthracnose

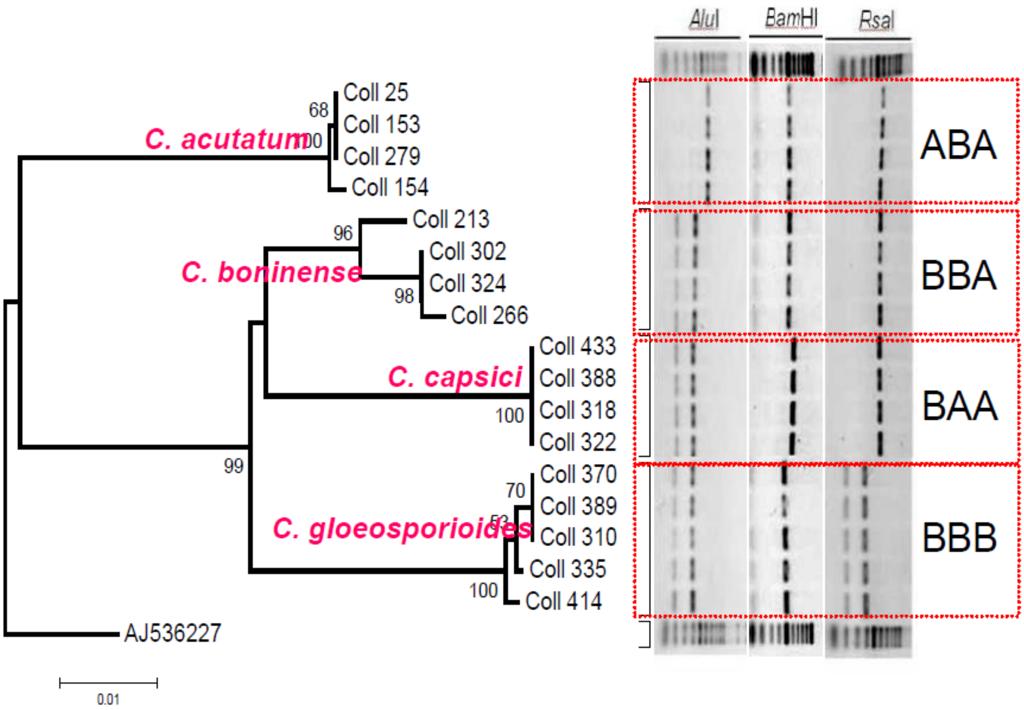
Zong-ming Sheu, Ming-hsueh Chiu & Jaw-Fen Wang

Internal transcribed spacer regions (ITS) of fungal rDNA



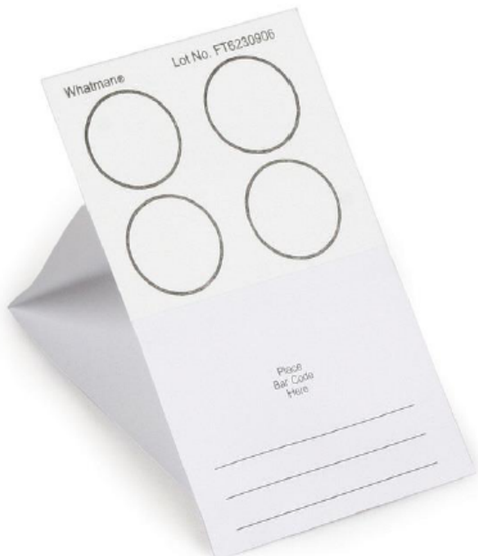
- Most widely sequenced region in fungi
- Useful for molecular systematics at the species level, and even within species
- Formally proposed as the primary fungal barcode marker (Schoch *et.al*,2012)

ITS-RFLP is used to differentiate *Colletotrichum* species associated with pepper anthracnose



What is FTA ®cards?

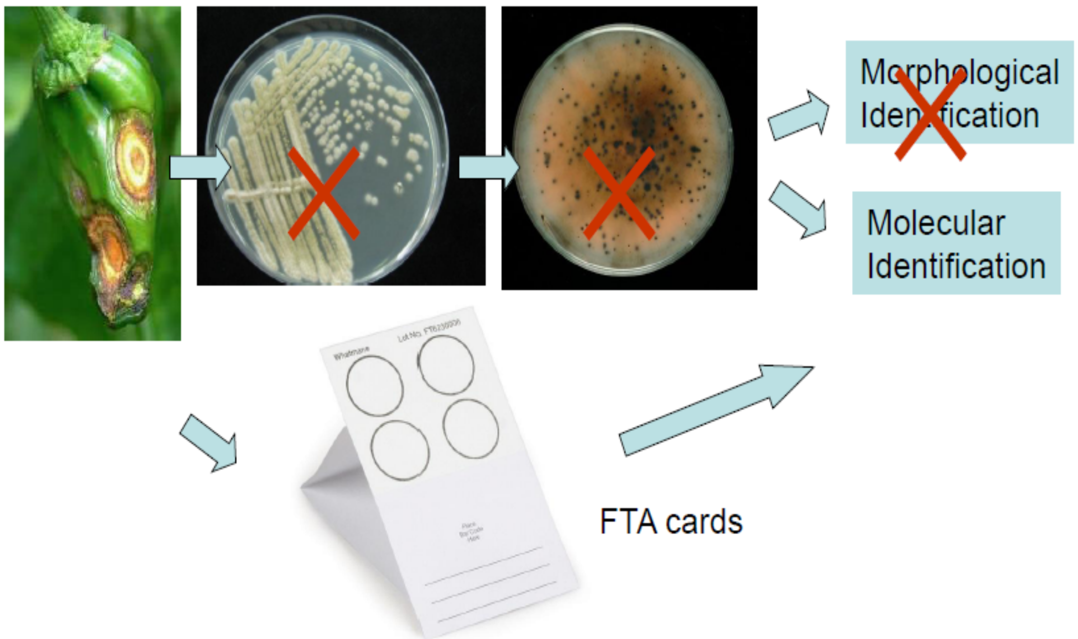
- Capture nucleic acid in one easy step
- DNA collected on FTA Cards can be preserved for years at RT
- Captured nucleic acid is ready for downstream applications
- Suitable for virtually any cell type
- FTA Cards are available in a variety of configurations to meet application requirements



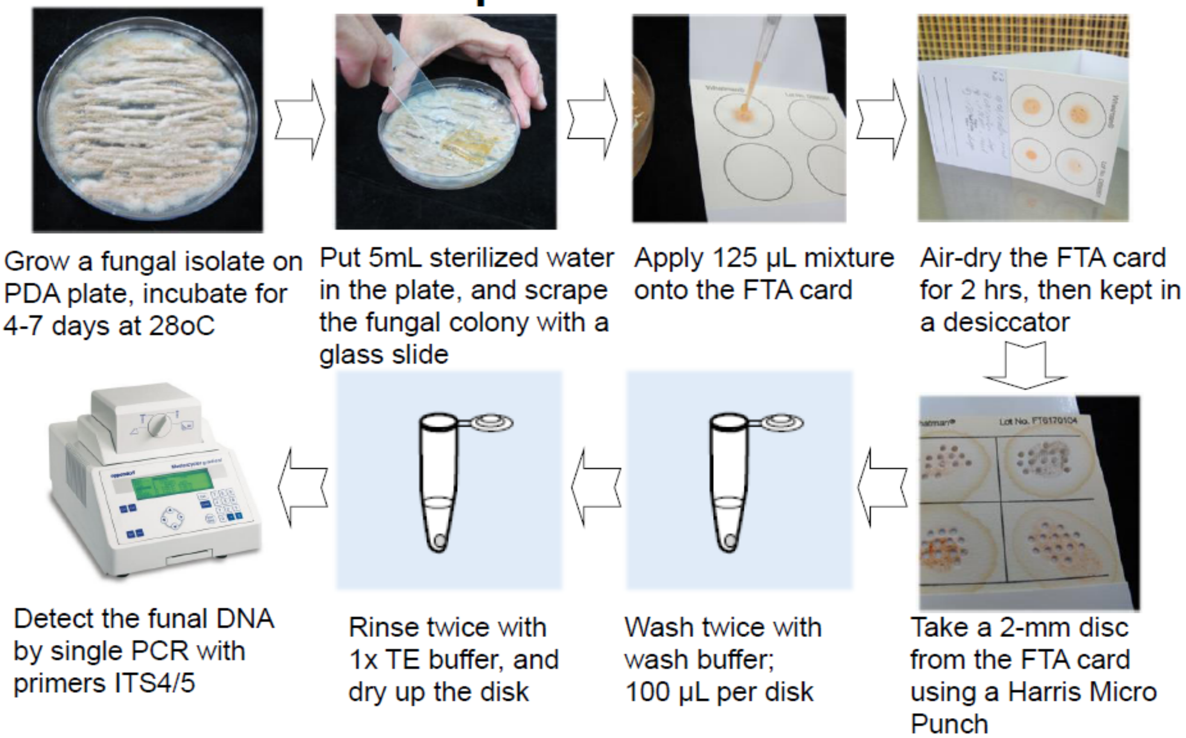
FTA ® Cards utilize patented Whatmn FTA ® technology that simplifies the handling and processing of nucleic acids.

The Objective:

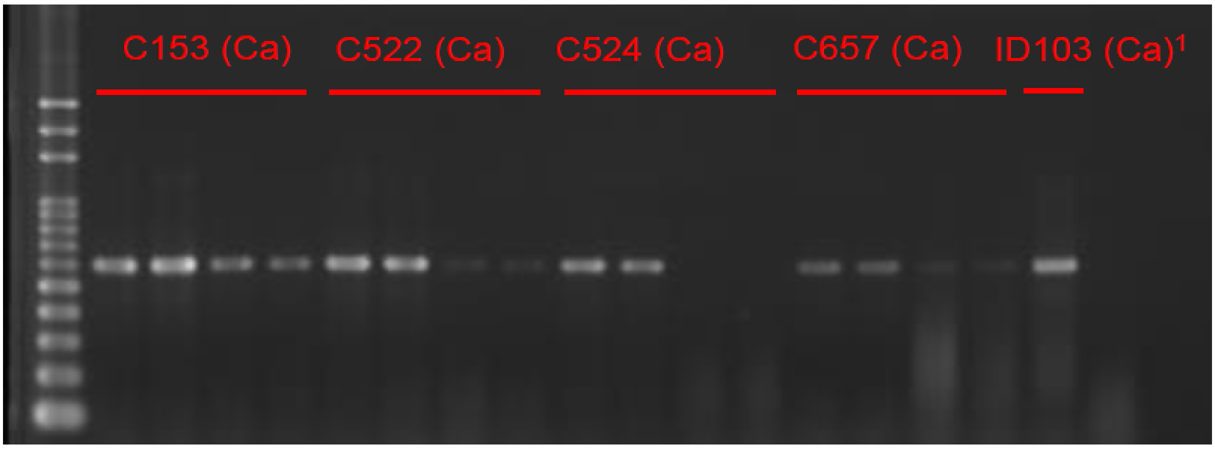
To evaluate the capacity and risk, and then develop an FTA® card-based protocol for identifying *Colletotrichum* species associated with pepper anthracnose



Preliminary test followed the product instruction with a pure culture of *C. acutaum*

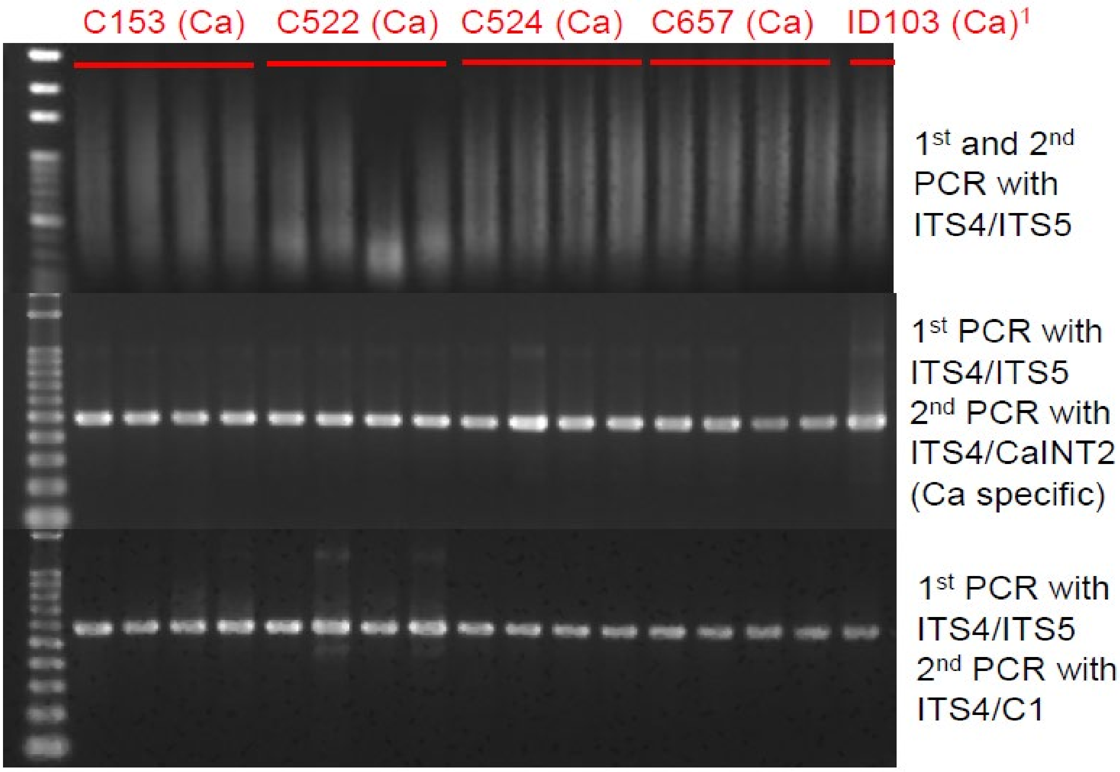


Variable intensity of amplicons from a single PCR reaction

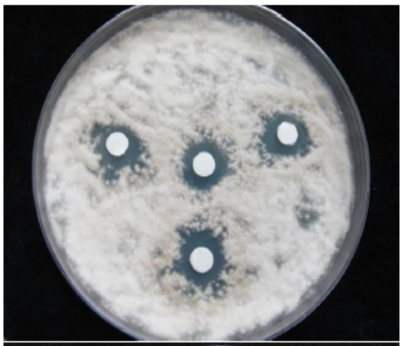


[1] ID103: a purified DNA extraced from Viogene Kit cat. GPG1001

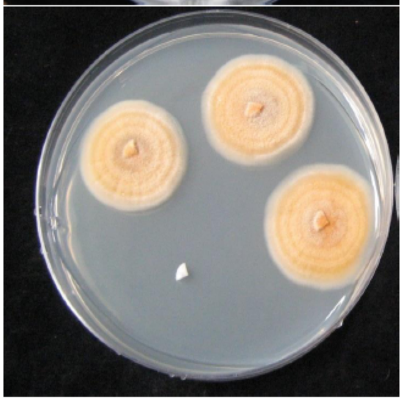
Nested PCR to amplify ITS



The FTA card inhibited the growth of *C. acutatum*, but didn't kill them all

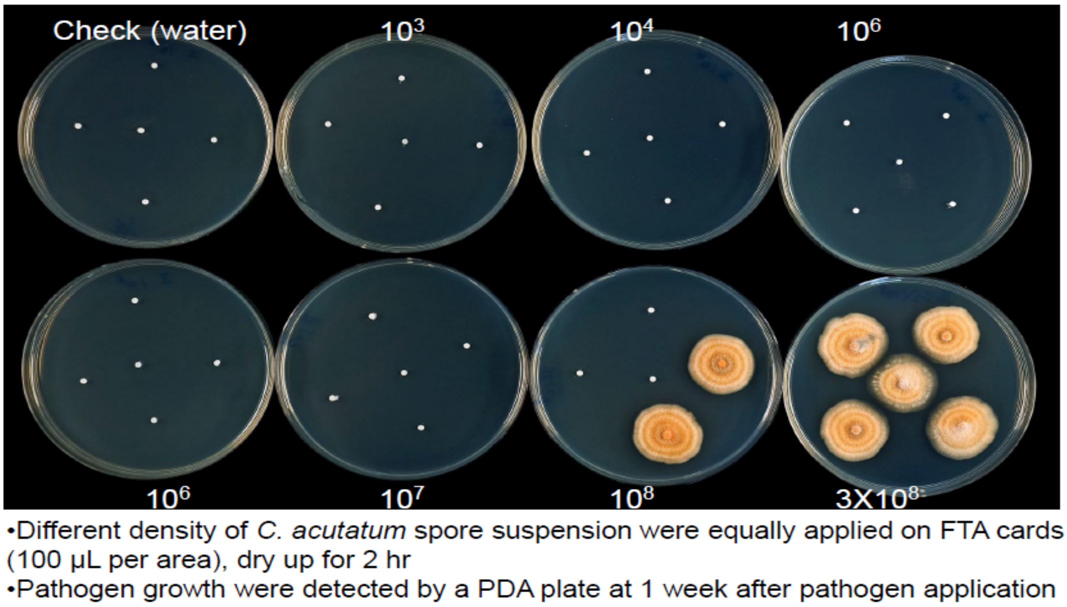


•Pathogen inhibition were observed on a PDA plate which spread with 1000 conidia spore and 4 blank FTA card disks (7mm in diameter)



•FTA cards applied with pure culture blend (estimated >10^{8} conidia/mL)
•Pathogen growth were detected by a PDA plate at 1 week after pathogen application

Complete growth inhibition when spore density <10^{7} spores/mL applied on FTA cards



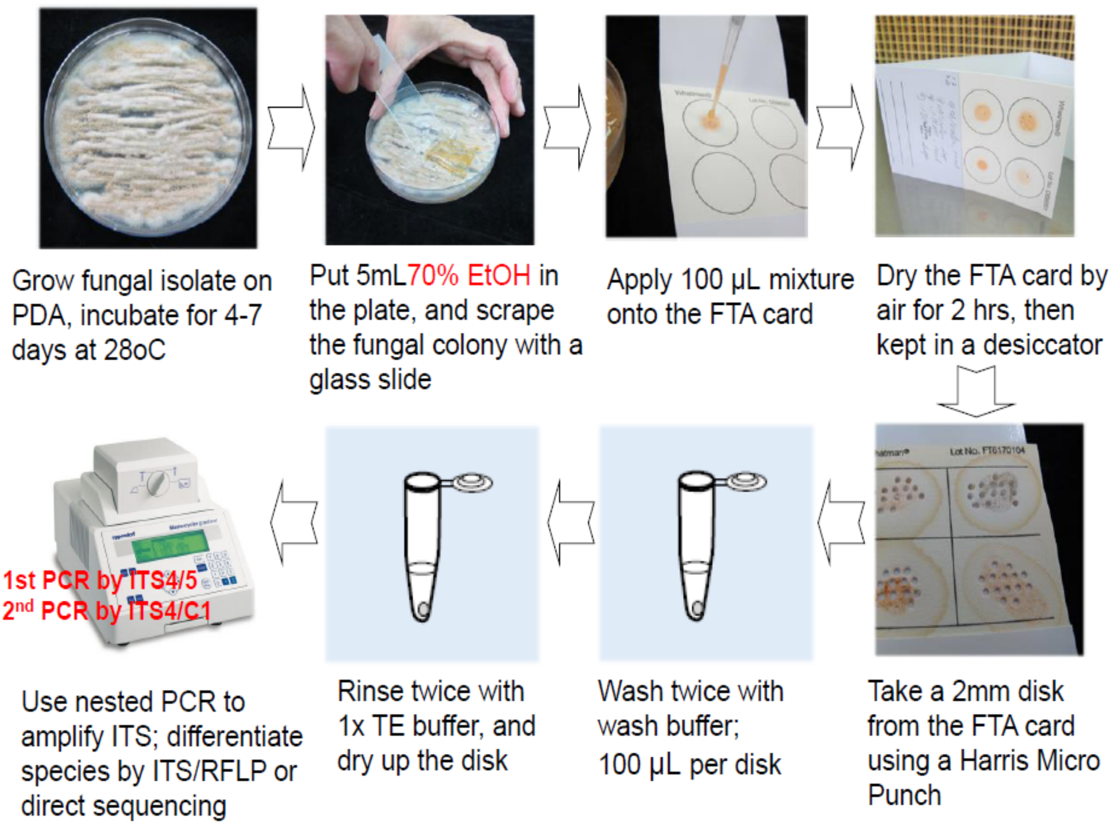
•Different density of *C. acutatum* spore suspension were equally applied on FTA cards (100 µL per area), dry up for 2 hr
•Pathogen growth were detected by a PDA plate at 1 week after pathogen application

Effect of ethanol or heat treatment on pathogen growth inhibition on the FTA® cards

Treatment	Growth on PDA (%)	1st PCR detection (%)	2 nd PCR detection (%)
Ethanol + heat-dry**	0	91.6-100	100
Ethanol + air-dry	0	91.6-100	100
Heat treatment**	0	91.6-100	100
Air-dry (check)	66.6	75-100	100

* Pure culture (>10^8 conidia/mL) applied on FTA card
** 50 C overnight

An improved protocol for pure culture

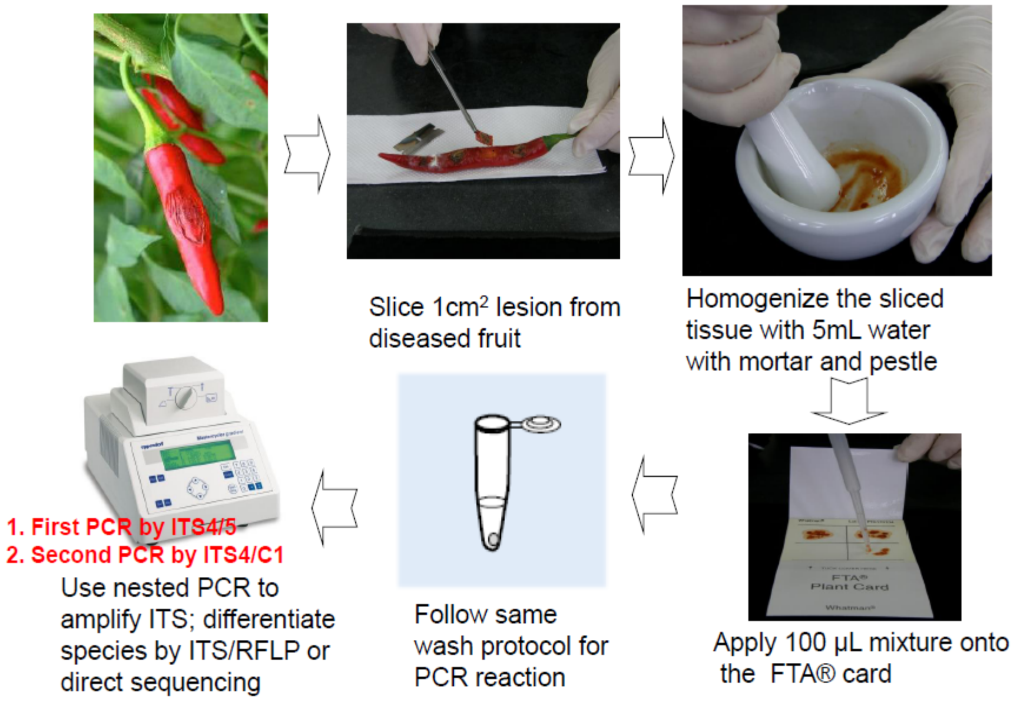


A case study on *Colletotrichum* isolates collected from Fiji

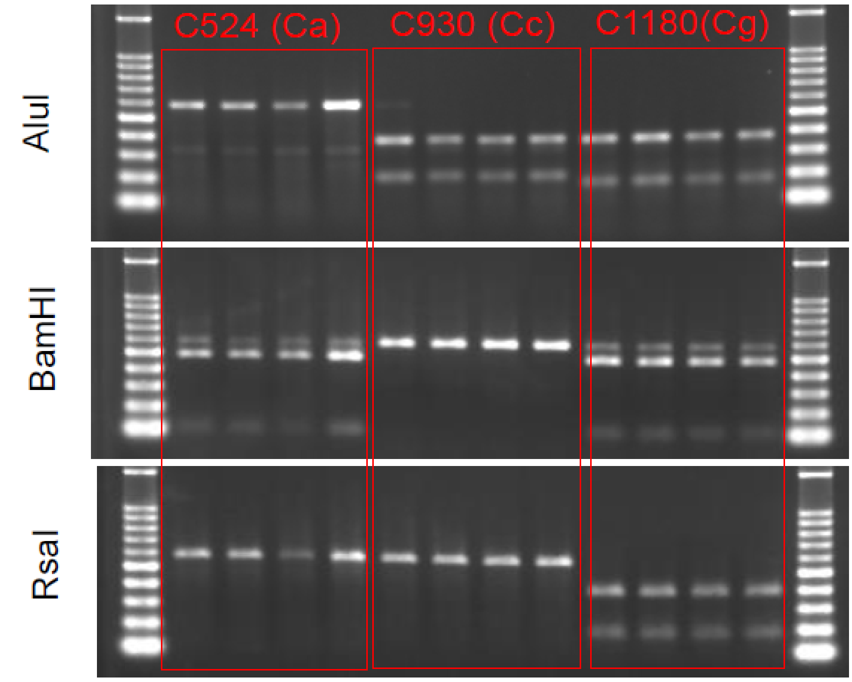
Isolate code	Species	Geographic origin			ITS/RFLP pattern
		Division	Province	location	
LG 02	*C. simmondsii*	Western	Ba	Nadi/LRS	ABA
LG 03	*C. simmondsii*	Western	Ba	Nadi/LRS	ABA*
LG 04	*C. simmondsii*	Western	Ba	Nadi/LRS	ABA*
LG 05	*C. simmondsii*	Western	Ba	Nadi/LRS	ABA*
LAU 02	*C. simmondsii*	Western	Ba	Lautoka	ABA
LAU 04	*C. truncatum*	Western	Ba	Lautoka	BAA*
LAU 06	*C. simmondsii*	Western	Ba	Lautoka	ABA*
LAU 07	*C. simmondsii*	Western	Ba	Lautoka	ABA
LAU08	*C. simmondsii*	Western	Ba	Lautoka	ABA
TAV03	*C. simmondsii*	Western	Ba	Tavua/Yaladro	ABA
RAK05	*C. simmondsii*	Western	Ra	Rakiraki/Naiyala	ABA
SR50	*C. simmondsii*	Western	Ra	Nalawa	ABA*
SR60	*C. simmondsii*	Northern	Macuta	Labasa	ABA*

* ITS sequenced

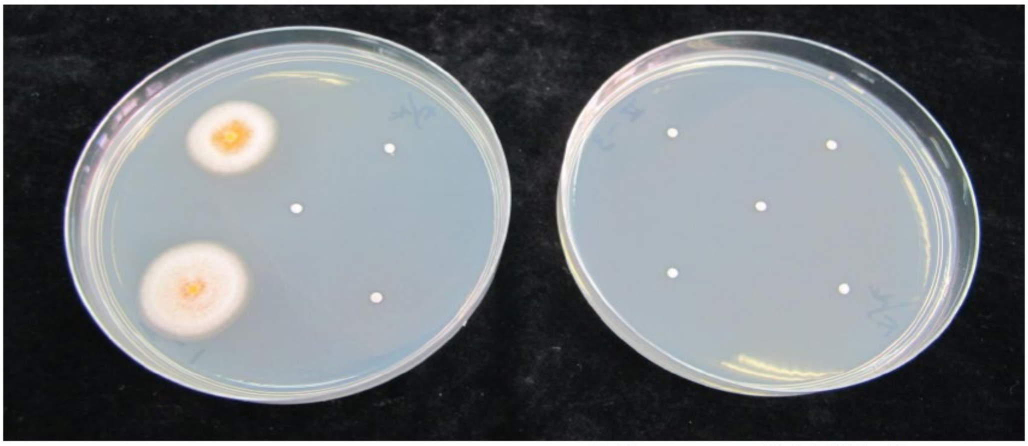
A pretest protocol for infected fruits



ITS/RFLP was successfully used to identify *Colletotrichum* species from inoculated fruits



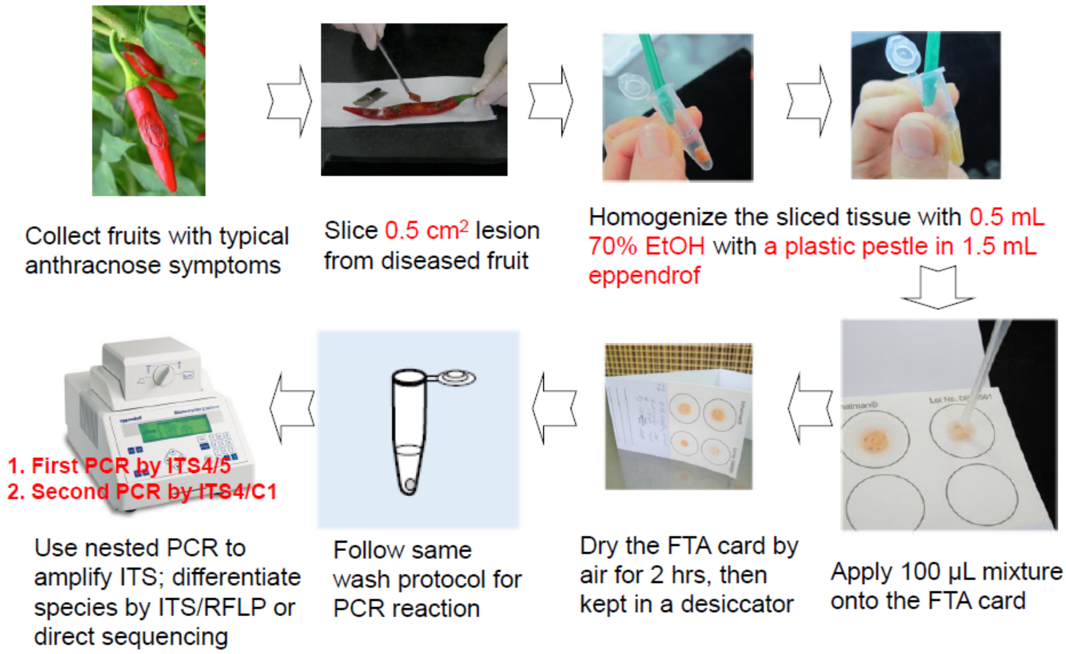
Pathogen survival through FTA® cards found when inoculated fruit was applied



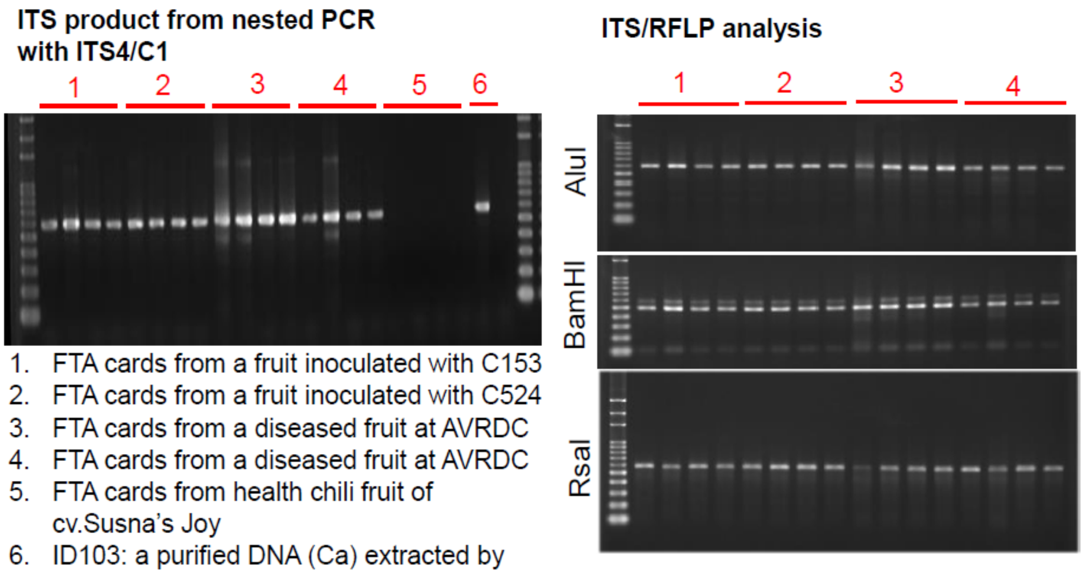
FTA card samples from a fruit inoculated with Ca

Pathogen growth inhibited by treatment with 70% EtOH

A revised sampling protocol for infected fruits



Use of the revised protocol to identify *Colletotrichum* species from 2 inoculated fruits and 2 naturally infected fruits from AVRDC



1. FTA cards from a fruit inoculated with C153
2. FTA cards from a fruit inoculated with C524
3. FTA cards from a diseased fruit at AVRDC
4. FTA cards from a diseased fruit at AVRDC
5. FTA cards from health chili fruit of cv.Susna's Joy
6. ID103: a purified DNA (Ca) extracted by Viogene Kit cat. GPG1001

11.4 Appendix 4: International Cooperators' Guide: Procedures for Tomato Variety Field Trials

AVRDC
The World Vegetable Center

AVRDC – The World Vegetable Center

AVRDC Publication Number: 11-751

International Cooperators' Guide

Procedures for Tomato Variety Field Trials

Peter Hanson, Li-ju Lin, Gregory C. Luther, Wen-shi Tsai, R. Srinivasan, Chien-hua Chen, Chih-hung Lin, Zong-ming Sheu and Shu-fen Lu

Introduction

The procedures described here allow comparison of the data collected in different test environments (locations, years, and seasons) by researchers participating in AVRDC multi-environment tomato variety trials. They could also be useful for other researchers interested in testing tomato varieties under local conditions.

Choice of land

Select a well-drained area with fairly uniform fertility and slope.

Number of entries

The suggested number of entries is from 5 to 20, which should include one or two locally popular varieties at each location (Table 1).

Experimental design

A randomized complete block design (RCBD) with three replications is recommended (Fig. 1). Each field trial has border rows on four sides.

Size of plot

Row length and plant spacing normally used in local production practices are recommended.

The minimum number of plants per plot is 12 (1-row planting for large entries, data is collected from the 10 inner plants). At AVRDC, each entry is grown on a 2-row, 4.8 m long and 1 m wide plot with furrows (ditches) 50 cm wide on each side. The distance between rows is 60 cm. Plant spacing within rows is 40 cm. Thus, each row accommodates 12 plants and a total of 24 plants per plot. Data is collected from the 20 inner plants. Any changes in plot dimensions should be reflected in the data sheet.

Cultural practices

For recommended cultural and pest management practices, please refer to:

Suggested Cultural Practices for Tomato
http://libnts.avrdc.org.tw/fulltext_pdf/E/1991-2000/e03437.pdf

Pruning and Staking Tomatoes
http://libnts.avrdc.org.tw/fulltext_pdf/E/1991-2000/e03439.pdf

Safer Tomato Production Techniques
http://libnts.avrdc.org.tw/fulltext_pdf/EB/2001-2010/eb0143.pdf

1

Table 1. Sample planting plan.

Entry code	Replication I Plots 1-8	Replication II Plots 9-16	Replication III Plots 17-24
A	8	12	17
B	7	16	22
C	5	10	20
D	4	15	21
E	2	11	19
F	3	13	18
G	1	14	24
H*	6	9	23

*Local check variety

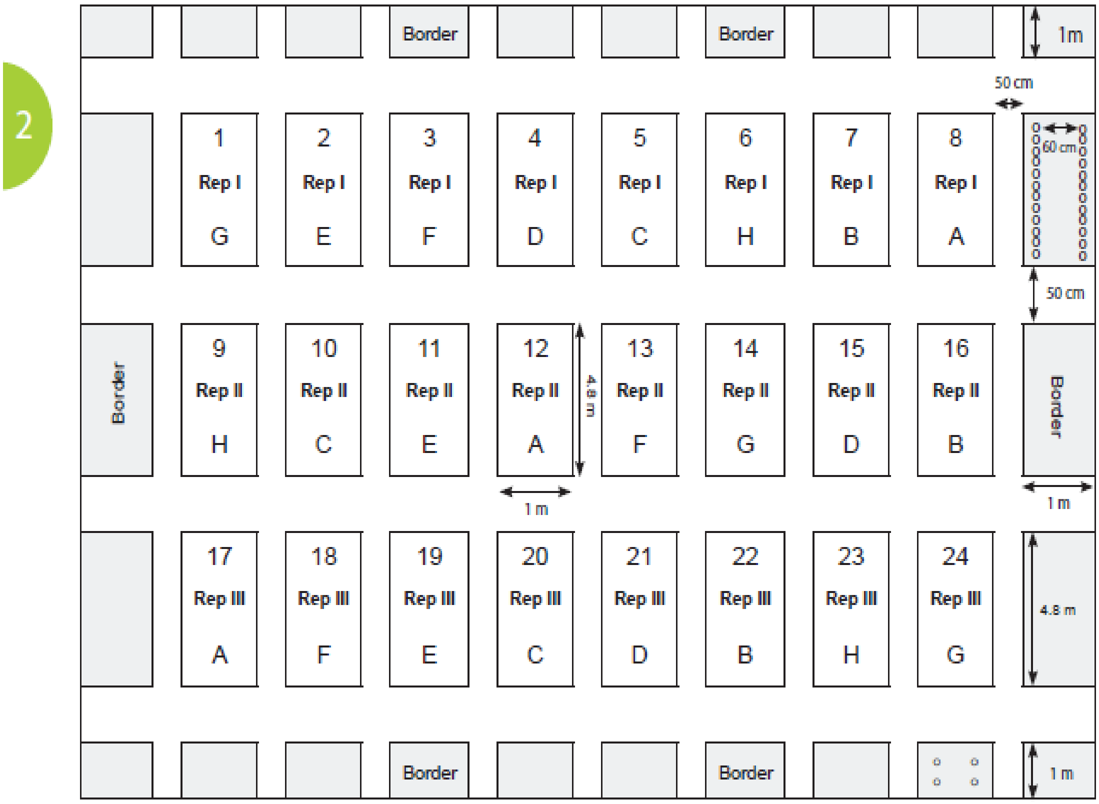


Figure. 1. *Sample field layout (the border area can have one or two rows of tomatoes).*

Harvesting

For fresh market tomato, start harvesting at breaker stage (less than 10% surface pink or red). For cherry tomato, harvest the whole fruit cluster when 80-90% turns red. For processing tomato, harvest red ripe fruit. At AVRDC, determinate tomato plants are generally harvested three times and indeterminate types four or more times. Record harvest dates and times (Table 2).

Data to collect

Researchers should keep a record of the basic characteristics of the trial site and the management practices employed when conducting a variety trial (Tables 2 & 3). This information can be useful for explaining varietal performance in different environments. Plant characteristics and reactions to biotic stresses, yield and its components to be collected for each plot are as follows:

1. ***Days to 50% flowering:***
   Number of days after transplanting when 50% of the plants in a plot have open flowers. Check plots three times a week (Table 4).

2. ***Growth habit:***
   (1) *determinate:* short and bushy, produces two leaves between flower clusters and about five clusters per branch; (2) *indeterminate:* tall, produces three leaves between flower clusters and more than six clusters per branch; (3) *semi-determinate:* taller than determinate types, but not as tall as indeterminate types (Table 4).

3. ***Biotic stress rating:***
   Entries are evaluated every 1-2 weeks when pest pressure (damage) is most serious. Check Figures 2 to 4 for the rating scales of early blight, late blight and tomato yellow leaf curl disease (TYLCD); and Figures 5 to 7 for wilt symptoms of fusarium wilt, bacterial wilt and southern blight to help you score and record the severity of diseases (Table 4). For insect damage, count and weigh the number of fruits damaged by tomato fruit borer (Tables 4 & 5).

4. ***Number of plants harvested:***
   Count the plants harvested from the 2-row plot. This will indicate population density and help explain low yields in plots with poor stands (Table 5).

5. ***Number of fruits and fruit yield:***
   Separate the marketable (worth selling) from nonmarketable fruits (with defects such as cracking, blossom end rot, graywall, blotchy ripening, puffiness, sunscald, catface, insect damaged fruits, etc.) after harvesting (Figure 8). Record the number and weight (kg/plot) of marketable and nonmarketable fruits. Repeat the process every time until harvesting is done. The total marketable yield is obtained by adding the yields of individual harvests (Table 5).

   The yield per plot (kg/plot) can be converted into tonnes per hectare with the following formula:

   $$\text{Yield (t/ha)} = \frac{\text{plot yield (kg) / 1,000 (kg/t)}}{\text{harvested area (m}^2\text{) / 10,000 (m}^2\text{/ha)}}$$

   Example:
   plot yield: 30 kg
   harvested area: 20 m^2

   $$\text{Yield} = \frac{30\text{ (kg) / 1,000 (kg/t)}}{20\text{ (m}^2\text{) / 10,000 (m}^2\text{/ha)}} = 15\text{ t/ha}$$

6. ***Fruit weight:***
   Average fruit weight (grams) can be calculated from 20 randomly selected marketable fruit per plot (Table 5).

   Example:
   Weight of 20 marketable fruits = 1,250 g

   $$\text{Average fruit weight} = \frac{1{,}250}{20} = 62.5\text{ g}$$

7. ***Remarks:***
   Any other interesting observations not recorded elsewhere that could help explain the outcome of the trial.

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Table 2. Data collection sheet for test location and crop management (1)

TOMATO VARIETY FIELD TRIALS: TEST LOCATION AND CROP MANAGEMENT DATA SHEET (1)

Country ____________
State / province / department ____________
District / town / city ____________
Farm or experiment station ____________
Institution ____________
Cooperator (s)/ data taker (s) ____________
E-mail: ____________

FIELD PLOT DATA
Plot width (m) ____________
Row length (m) ____________
No. of rows / plot ____________
No. of plants / row ____________
Spacing between rows (cm) ____________
Plant spacing within rows (cm) ____________

LATITUDE degrees minutes N or S ☐☐ ☐☐ ☐☐

LONGITUDE degrees minutes E or W ☐☐☐ ☐☐ ☐☐

ALTITUDE above sea level ☐☐☐☐m

SOIL Classification ____________ Previous crop ____________

surface texture		surface pH		drainage condition	
sandy		unknown		excellent	
sandy loam		> 8		very good	
loam		7.1 - 8		good	
clay loam		5.6 - 7		average	
silty clay		4 - 5.5		poor	
clay		< 4		very poor	
other		or			

If other, specify ____________ actual value ____________

PLANTING SCHEDULE
date sown (day ☐☐ month ☐☐ year ☐☐☐☐) date transplanted (day ☐☐ month ☐☐ year ☐☐☐☐)

HARVEST
start date (day ☐☐ month ☐☐ year ☐☐☐☐) end date (day ☐☐ month ☐☐ year ☐☐☐☐) Number of times harvested ____________

FERTILIZER APPLIED? ☐ Yes ☐ No Specify unit of fertilizer applied if different from kg/ha ____________

applied	day	month	year	quantity kg/ha	%N	$\%P_2O_5$	$\%K_2O$	Other element(s)
1st date								
2nd date								
3rd date								

IRRIGATION ? ☐ Yes ☐ No If Yes, please specify methods and frequency

methods		frequency	
Drip		weekly	
Furrow		twice a month	
Sprinkler		monthly	
Other		other	

If other, specify ____________ If other, specify ____________

OTHER PRACTICES
☐ Mulching ☐ Staking ☐ Others, please specify ____________

4

Table 3. Data collection sheet for test location and crop management (2)

TOMATO VARIETY FIELD TRIALS: TEST LOCATION AND CROP MANAGEMENT DATA SHEET (2)

Country ______	**FIELD PLOT DATA**
State / province / department ______	Plot width (m) ______
District / town / city ______	Row length (m) ______
Farm or experiment station ______	No. of rows / plot ______
Institution ______	No. of plants / row ______
Cooperator (s)/ data taker (s) ______	Spacing between rows (cm) ______
E-mail: ______	Plant spacing within rows (cm) ______

PROBLEM CHECKLIST

	foliar disease	root disease	insect or mite damage	rat or bird damage	herbicide damage	weed problem
none						
trace						
slight						
moderate						
severe						

IF A DISEASE PROBLEM IS MODERATE OR SEVERE, PLEASE SPECIFY:

MAJOR DISEASE OBSERVED (OR SYMPTOMS) ______

CONTROL MEASURES AND DATE(S) APPLIED ______

IF A INSECT OR MITE PROBLEM IS MODERATE OR SEVERE, PLEASE SPECIFY:

MAJOR INSECT OBSERVED ______

CONTROL MEASURES AND DATE(S) APPLIED ______

IF A WEED PROBLEM IS MODERATE OR SEVERE, PLEASE SPECIFY:

MAJOR SPECIES, CONTROL MEASURES AND DATE(S) APPLIED ______

CHEMICALS APPLIED ? ☐ Yes ☐ No

HERBICIDE ☐ Yes ☐ No **If Yes, specify product (s)** ______

FUNGICIDE ☐ Yes ☐ No **If Yes, specify product (s)** ______

INSECTICIDE ☐ Yes ☐ No **If Yes, specify product (s)** ______

OTHERS ☐ Yes ☐ No **If Yes, specify product (s)** ______

DATES APPLIED (DD/MM/YY)	**Herbicide**	**Fungicide**	**Insecticide**	**Others**
1st spray	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐
2nd spray	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐
3rd spray	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐	☐☐ ☐☐ ☐☐☐☐

CLIMATE DATA DURING TRIAL ☐ **Rainy season** ☐ **Dry season**

Average min. temp. ☐☐°C **Average max. temp.** ☐☐°C **Total rainfall** ☐☐☐☐mm

Remarks about deviations from normal ______

______

5

Table 4. Data collection sheet for plant characteristics and reactions to biotic stresses.

Plot no.	Rep	Entry code	Days to 50% flowering	Growth habit[1]	Disease rating						Insect damage
					EB[2]	LB[2]	TYLCD[3]	BW[4]	FW[4]	SB[4]	TFB[5]
1	1	G									
2	1	E									
3	1	F									
4	1	D									
5	1	C									
6	1	H									
7	1	B									
8	1	A									
9	2	H									
10	2	C									
11	2	E									
12	2	A									
13	2	F									
14	2	G									
15	2	D									
16	2	B									
17	3	A									
18	3	F									
19	3	E									
20	3	C									
21	3	D									
22	3	B									
23	3	H									
24	3	G									

[1] D: determinate type; ID: indeterminate type; SD: semi-determinate type
[2] EB (= early blight) and LB (= late blight): rate the plants at one of three levels, 0 = healthy, 1 = slight, 2 = severe
[3] TYLCD (= tomato yellow leaf curl disease): rate the plants at one of four levels, 0 = healthy, 1 = slight, 2 = moderate, 3 = severe
[4] BW (= bacterial wilt), FW (= fusarium wilt) and SB (= southern blight): record number of wilted plants
[5] TFB (= tomato fruit borer): record number of TFB damaged fruits

Table 5. Data sheet to track yield and yield components.

Plot no.	Rep	Entry code	No. of plants harvested	Average fruit weight (g)	Fruit yield (kg/plot)												Total marketable fruit weight (kg)
					1st harvest ( )			2nd harvest ( )			3rd harvest ( )			4th harvest ( )			
					M[1]	NM[2]	TFB[3]	M[1]	NM[2]	TFB[3]	M[1]	NM[2]	TFB[3]	M[1]	NM[2]	TFB[3]	
1	1	G															
2	1	E															
3	1	F															
4	1	D															
5	1	C															
6	1	H															
7	1	B															
8	1	A															
9	2	H															
10	2	C															
11	2	E															
12	2	A															
13	2	F															
14	2	G															
15	2	D															
16	2	B															
17	3	A															
18	3	F															
19	3	E															
20	3	C															
21	3	D															
22	3	B															
23	3	H															
24	3	G															

( ) indicate the date of harvest. Add more columns if there are more than 4 harvests.
[1] M: marketable fruits
[2] NM: nonmarketable fruits
[3] TFB: tomato fruit borer damaged fruits

Figure 2. *Early blight rating scale: 0 = no symptoms, 1 = dark circular spots start on the old leaves, 2 = leaves dry and falling off.*

Figure 3. *Late blight rating scale: 0 = no symptoms, 1 = irregular dark, water-soaked spots develop on leaves and the undersides of lesions may be covered by a white fuzzy growth, 2 = brown to black lesions appear on stems and shiny, dark or olive-colored lesions develop on fruits.*

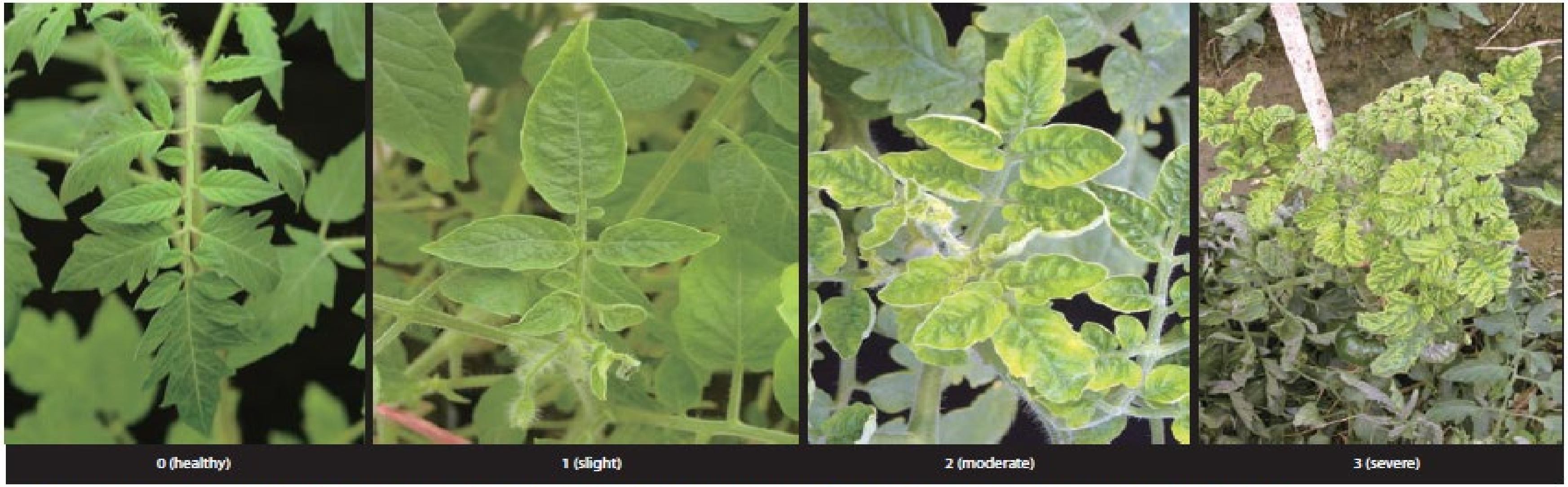

Figure 4. *Tomato yellow leaf curl disease rating scale: 0 = no symptoms, 1 = curling of upper leaves, 2 = curling, blistering and yellowing of leaves, 3 = stunting and distortion.*

Figure 5. *Symptoms of fusarium wilt: Yellowing begins on lower leaves and eventually leads to leaf drop and plant wilt.*

Figure 6. *Typical symptoms of bacterial wilt first appear as drooping of a few young leaves. A sudden complete wilt soon follows. Infected plants display wilting but not yellowing leaves. Most of the time, leaves are still green when the plants wilt.*

Figure 7. *Symptoms of southern blight: White fungal growth is produced on the stem at the soil line and mustard seed-sized, round, tan to dark brown structures appear on the white fungal growth, leading to a rapid wilting of the entire plant.*

Figure 8. *Nonmarketable tomato fruits.*

1. Cracking
2. Blossom end rot
3. Graywall
4. Catface
5. Puffiness
6. Sunscald
7. Blotchy ripening
8. Damage by tomato fruit borer

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This guide and Excel format data sheets are available online at www.avrdc.org/index.php?id=746

12/2011

11.5 Appendix 5: International Cooperators' Guide: Procedures for Sweet Pepper Variety Field Trials

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AVRDC Publication Number: 14-775

International Cooperators'

Guide

Procedures for Sweet Pepper Variety Field Trials

Hsueh-ching Shieh, Shih-wen Lin, Li-ju Lin, Zong-ming Sheu, Wen-shi Tsai, R. Srinivasan and Sanjeet Kumar

Introduction

This guideline provides suggestions to for evaluating sweet pepper lines. Following this, the data recorded at different locations can be compared by researchers participating in AVRDC's International Sweet Pepper Nnursery (ISPN) trials and other varietal evaluation trials.

Choice of land

Select a well-drained area with fairly uniform fertility and slope.

Number of entries

The suggested number of entries is from 5 to 15 (or entries included in the ISPN), which should include two or three locally popular cultivars (open pollinated [OP] or hybrids) at each location as checks (Table 1).

Experimental design

A randomized complete block design (RCBD) with three replications is recommended. Each field trial has border rows on four sides (Fig. 1).

Size of plot

Row length and plant spacing normally used in local production practices are recommended. At AVRDC, each entry is grown on a 30-cm high raised bed with 2-row planting. The plot size is 5.4 m long and 1.5 m wide between furrows (Fig. 1). The distance between rows is 50 cm. Plant spacing within rows is 45 cm. Thus, there would be a total of 24 plants planted in each plot and 12 plants per row. The plant density is 29,630 plants/ha. For a large number of entries, 1-row planting can be applied and the total number of plants per plot should be 12. Any changes in plot dimensions should be reflected in the data sheet.

Cultural practices

For recommended cultural and pest management practices, please refer to:

Suggested Cultural Practices for Sweet Pepper
http://avrdc.org/?wpfb_dl=1260

1

Table 1. Sample planting plan

Entry code	Replication		
	I	II	III
	Plots 1-8	Plots 9-16	Plots 17-24
E01	8	12	17
E02	7	16	22
E03	5	10	20
E04	4	15	21
E05	2	11	19
E06	3	13	18
E07	1	14	24
E08*	6	9	23

*Local check cultivar

2

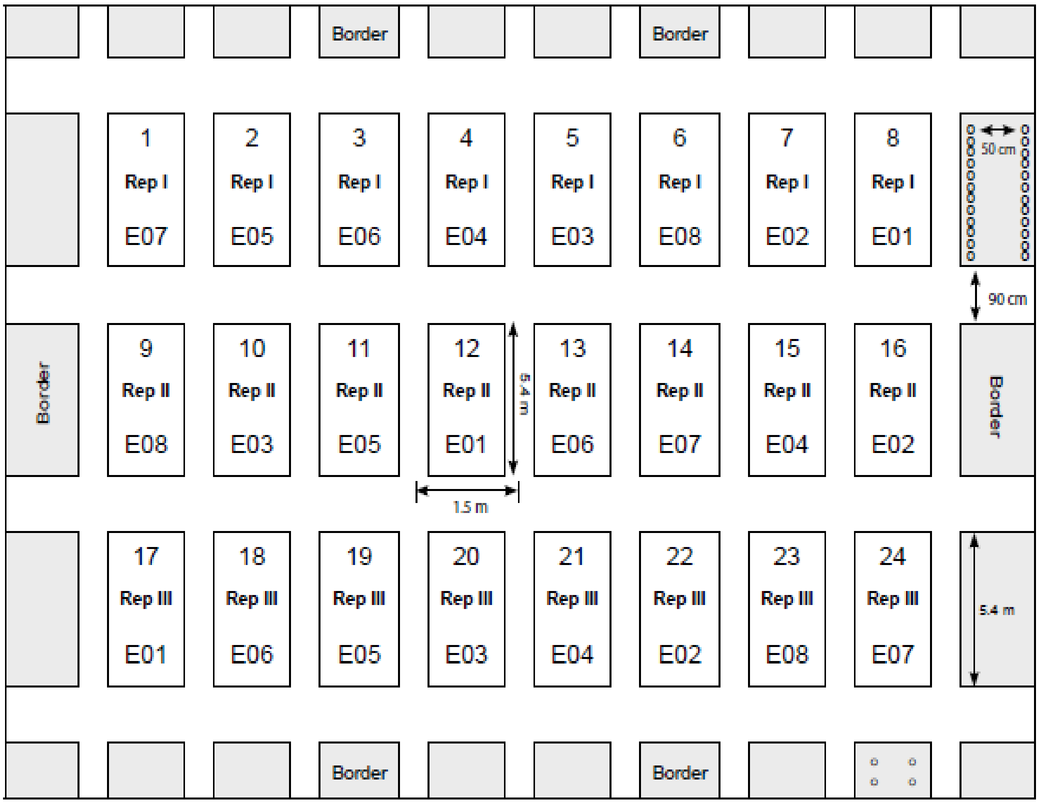

Figure 1. *Sample field layout for 2-row planting (the border area can have one or two rows of sweet pepper). The suggested distance between furrows is 1.5 m for 2-row planting or 1 m for 1-row planting.*

Harvesting

During the initial plant growth stage, pinch off the flower buds and/or small developing fruits at first and second nodes. Harvest the fruit when fruits reach full size and become firm at the green mature stage, just before mature color begins to develop. It usually takes 50–60 days from flowering to optimum harvest stage.

Data to collect

Researchers should keep a record of the basic characteristics of the trial site and the management practices employed when conducting a variety trial (Table 2). This information can be useful for explaining varietal performance in different environments. For 2-row planting, data is collected from 20 inner plants. For 1-row planting, data is collected from 10 inner plants. Plant characteristics and reactions to biotic stresses, yield and its components to be collected for each plot are as follows:

1. Days to 50% flowering:

Number of days after transplanting (DAT) to 50% anthesis (50% of plants in a plot have open flowers at the second node). Check plots three times a week and record on Table 3.

2. Days to 50% maturity:

Number of days after transplanting (DAT) to 50% maturity (50% of plants in a plot have green mature fruits ready to harvest or have turned to yellow or red color). Check plots three times a week and record on Table 3.

3. Biotic stress rating:

Evaluate incidence of diseases and insects when the first harvest is done. Record incidence as R (=resistant, 70-100% of plants per plot are healthy), MR (=moderate resistant, 50-70% of plants per plot are healthy), MS (=moderate susceptible, 20-50% of plants per plot are healthy) or S (=susceptible, 0-20% of plants per plot are healthy). Check figures 2-6 for the symptoms of bacterial spot, bacterial wilt, Phytophthora blight, anthracnose and virus; and figures 7-9 for insect damage symptoms to help you identify, score and record the severity of pests (Table 3).

4. Number of plants harvested:

Count the plants harvested from the 2-row or 1-row plot. This will indicate population density and help explain low yields in plots with poor stands (Table 4).

5. Fresh fruit yield:

Separate the marketable (worth selling) from nonmarketable fruits (damaged due to biotic and abiotic stress or remarkably tiny fruits) after harvesting. Record weight of marketable and nonmarketable fruits from each plot and the harvest dates. Repeat the process for four harvests. The total marketable yield is obtained by adding the yields of individual harvests (Table 4).

The yield per plot (kg/plot) can be converted into tonnes per hectare with the following formula:

$$\text{Yield (t/ha)} = \frac{\text{plot yield (kg) / 1,000 (kg/t)}}{\text{harvested area (m}^2\text{) / 10,000 (m}^2\text{/ha)}}$$

Example of 2-row planting (data collected from 20 inner plants):

plot yield: 40 kg

harvested area: 6.75 m^2 (=0.45 m x 10 plants x 1.5 m)

$$\text{Yield} = \frac{\text{40 (kg) / 1,000 (kg/t)}}{\text{6.75 (m}^2\text{) / 10,000 (m}^2\text{/ha)}} = \text{59.3 t/ha}$$

6. Fruit length, width and weight:

Average fruit length (cm), width (cm) and weight (grams) can be calculated from 10 randomly selected marketable fruits in the first or second harvest (Table 4).

Example:

Total weight of 10 marketable fruits = 1,300 g

$$\text{Average fruit weight} = \frac{1{,}300}{10} = 130\text{ g}$$

7. Remarks:

Any other interesting observations not recorded elsewhere that could help explain the outcome of the trial (Table 3).

3

Table 2. Sample data sheet for test location and crop management

SWEET PEPPER VARIETY FIELD TRIALS: TEST LOCATION AND CROP MANAGEMENT DATA SHEET

Country ____________________

Cooperator(s) / data taker(s) ____________________

E-mail / address: ____________________

LOCATION DATA

Farm or experiment station ____________________

State / province / department ____________________

LATITUDE degrees minutes N or S ☐☐ ☐☐ ☐☐ LONGITUDE degrees minutes E or W ☐☐☐ ☐☐ ☐☐ ALTITUDE above sea level ☐☐☐☐m

SOIL Previous crop ____________________

Surface texture ☐ sandy loam ☐ clay loam ☐ silty loam ☐ other ____________________

Surface pH ☐>7 ☐6-7 ☐<6 or actual value ____________________

CLIMATE DATA DURING TRIAL ☐ Hot-wet ☐ Hot-dry ☐ Cool-dry ☐ Cool-wet ☐ Other

Average min. temp. ☐☐℃ Average max. temp. ☐☐℃ Total rainfall ☐☐☐☐mm

Remarks about deviations from normal ____________________

EXPERIMENT DATA

PLOT DATA Plot width (m) ______ Plot length (m) ______ Spacing between rows (cm) ______

No. of plants/plot ______ No. of rows/plot ______ Plant spacing within row (cm) ______

SEEDLING MANAGEMENT ☐ bare root ☐ seedling tray ☐ other ____________________

PLANTING SCHEDULE day month year — date sown ☐☐ ☐☐ ☐☐☐☐ — day month year — date transplanted ☐☐ ☐☐ ☐☐☐☐

HARVEST 1st ☐☐/☐☐ 2nd ☐☐/☐☐ 3rd ☐☐/☐☐ 4th ☐☐/☐☐ (day/month)

OTHER PRACTICES ☐ Mulching ☐ Staking ☐ Others, please specify ____________________

BIOTIC STRESSES OBSERVED AND CONTROL

Diseases: ☐ bacterial spot ☐ bacterial wilt ☐ Phytophthora blight

☐ anthracnose ☐ virus ☐ others ____________________

Control methods: ☐ chemicals applied ☐ others ____________________

Insects: ☐ broad mite ☐ aphid ☐ thrips ☐ others ____________________

Control methods: ☐ chemicals applied ☐ others ____________________

In your opinion, considering yield, plant type, fruit acceptability to local consumers, and other factors, which are the four best sweet pepper lines?

1 ____________________

2 ____________________

3 ____________________

4 ____________________

4

Table 3. Sample data sheet for plant characteristics and reactions to biotic stresses

Plot no.	Rep	Entry code	Days to 50% flowering	Days to 50% maturity	Incidence of diseases and insects*							Remarks
					BS	BW	PB	Virus	BM	Aphid	Thrips	
1	1	E07										
2	1	E05										
3	1	E06										
4	1	E04										
5	1	E03										
6	1	E08										
7	1	E02										
8	1	E01										
9	2	E08										
10	2	E03										
11	2	E05										
12	2	E01										
13	2	E06										
14	2	E07										
15	2	E04										
16	2	E02										
17	3	E01										
18	3	E06										
19	3	E05										
20	3	E03										
21	3	E04										
22	3	E02										
23	3	E08										
24	3	E07										

* BS (= bacterial spot), BW (= bacterial wilt), PB (= Phytophthora blight), Virus (= virus like symptoms), BM (= broad mite)

Rate the plants when the first harvest is done at one of four levels: **R** (=resistant, 70-100% healthy plants/plot)
MR (=moderate resistant, 50-70% healthy plants/plot)
MS (=moderate susceptible, 20-50% healthy plants/plot)
S (=susceptible, 0-20% healthy plants/plot)

5

Table 4. Sample data sheet to track yield and yield components

Plot no.	Rep	Entry code	No of plants harvested	Average fruit			Fruit yield (kg/plot)								Total M[2] wt. (kg)
				L[1] (cm)	Wd[1] (cm)	Wt.[1] (g)	1st harvest ( )		2nd harvest ( )		3rd harvest ( )		4th harvest ( )		
							M[2]	NM[2]	M[2]	NM[2]	M[2]	NM[2]	M[2]	NM[2]	
1	1	E07													
2	1	E05													
3	1	E06													
4	1	E04													
5	1	E03													
6	1	E08													
7	1	E02													
8	1	E01													
9	2	E08													
10	2	E03													
11	2	E05													
12	2	E01													
13	2	E06													
14	2	E07													
15	2	E04													
16	2	E02													
17	3	E01													
18	3	E06													
19	3	E05													
20	3	E03													
21	3	E04													
22	3	E02													
23	3	E08													
24	3	E07													

( ) indicate the date of harvest. Add more rows if there are more than 8 entries.
[1] L: length; Wd: width; Wt.: weight
[2] M: marketable fruits; NM: nonmarketable fruits

6

*Figure 2. Typical symptoms of **bacterial spot** (BS) first appear as tiny water-soaked spots, and became necrotic lesions surrounded by a yellow halo. Lesions may be sunken on the upper surface and slightly raised on the underside of the leaf. Dark spots and elongated lesions can be found on stem, petioles, peduncles and fruits. Please observe the incidence and rate the plants in Table 3.*

7

*Figure 3. Typical symptoms of **bacterial wilt** (BW) first appear as drooping of a few young leaves. A sudden complete wilt soon follows. Infected plants display wilting with little or no yellowing leaves (left). The disease can be correctly diagnosed by observing bacterial streaming from vascular system in the lower stem using a stem-ooze test (right). Please observe the incidence and rate the plants in Table 3.*

***Figure 4**. The first symptom of **Phytophthora blight** (PB) on pepper in the field is commonly crown rot (3). A lesion girdling the base of the stem (4) causes rapid collapse and death of the plant (1 & 5). Following rainstorms, some typical symptoms such as water-soaked lesions on leaves and fruits, and brown to dark purplish lesion on upper stem can be found (2). All plant parts including roots, crowns, stems, leaves, and fruit at any growth stage can be attacked. The wilting symptom is very similar to bacterial wilt if no foliar infection occurs. However, no bacterial streaming can be found using a stem-ooze test. Please observe the incidence and rate the plants in Table 3.*

Figure 5. *Typical symptoms of* ***anthracnose*** *are usually on fruits at both immature and mature stage. The symptoms initially begin as water-soaked lesions that become sunken and tan. The lesions expand soon and eventually produce gelatinous, salmon-colored conidia spores. Concentric rings of the acervuli are common within the lesion. In some cases, the lesions are dark due to the formation of numerous black setae or other fungal tissue. Please observe the incidence and record in Table 2.*

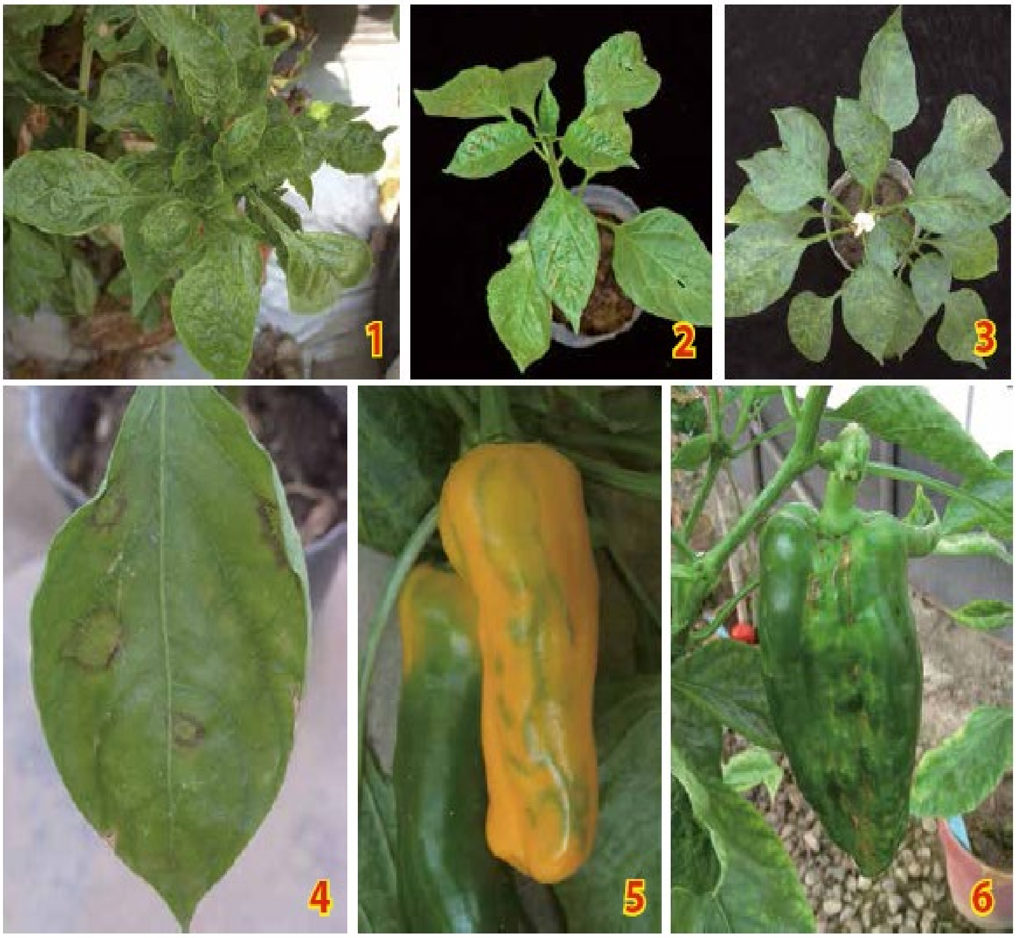

Figure 6. ***Virus-*** *like symptoms include vein yellowing, yellow, brown ring and necrotic spots, mosaic and mottle leaves (1-4) and deformation, green rings, necrotic spots and yellow strips on fruits (5 & 6). Please observe the incidence and rate the plants in Table 3.*

Figure 7*. The symptoms of* ***aphid*** *damaged plants include leaf distortion and mottling; chlorotic leaf spots and black sooty mold. Please observe the incidence and rate the plants in Table 3.*

Figure 8*. The symptoms of* ***broad mite*** *damaged plants include leaves curling downwards; growing point and young leaves are bronzed and stunted; necrosis on the growing point and dropping of old leaves; and cork-like fruits. Please observe the incidence and rate the plants in Table 3.*

10

Figure 9*. The symptoms of* ***thrips*** *damaged plants include young leaves curling upwards; fruits netted with cork-like streaks; plants stunted with small leaves on young shoots. Please observe the incidence and rate the plants in Table 3.*

The Excel format data sheets are available online at http://avrdc.org/?page_id=223.

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03/2014

11.6 Appendix 6: International Cooperators' Guide: Procedures for Chili Pepper Variety Field Trials

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AVRDC Publication Number: 14-784

International Cooperators'

Guide

Procedures for Chili Pepper Variety Field Trials

Shih-wen Lin, Hsueh-ching Shieh, Li-ju Lin, Zong-ming Sheu, Lawrence Kenyon, R. Srinivasan and Sanjeet Kumar

Introduction

This guideline provides suggestions to evaluate chili pepper lines. Following this, the data recorded at different locations can be compared by the researchers participating in AVRDC's International Chili Pepper Nursery (ICPN) trials and other varietal evaluation trials.

Choice of land

Select a well-drained area with fairly uniform fertility and slope.

Number of entries

The suggested number of entries is from 5 to 20 (or entries included in the ICPN), which should include two or three locally popular cultivars (open pollinated [OP] or hybrids) at each location as checks (Table 1).

Experimental design

A randomized complete block design (RCBD) with three replications is recommended. Each field trial has border rows on four sides (Figure 1).

Size of plot

Row length and plant spacing normally used in local production practices are recommended. At AVRDC, each entry is grown on a 30-cm high raised bed with 2-row planting. The plot size is 5.4 m long and 1.5 m wide between furrows (Figure 1). The distance between rows is 50 cm. Plant spacing within rows is 45 cm. Thus, there would be a total of 24 plants planted in each plot and 12 plants per row. The plant density is 29,630 plants/ha. For a large number of entries, 1-row planting can be applied and the total number of plants per plot should be 12. Any changes in plot dimensions should be reflected in the data sheet.

Cultural practices

For recommended cultural and pest management practices, please refer to:

Suggested Cultural Practices for Chili Pepper
http://203.64.245.61/web_crops/pepper/chili_pepper.pdf

Table 1. Sample planting plan.

Entry code	Replication		
	I	II	III
	Plots 1-8	Plots 9-16	Plots 17-24
E01	8	12	17
E02	7	16	22
E03	5	10	20
E04	4	15	21
E05	2	11	19
E06	3	13	18
E07	1	14	24
E08*	6	9	23

*Local check cultivar

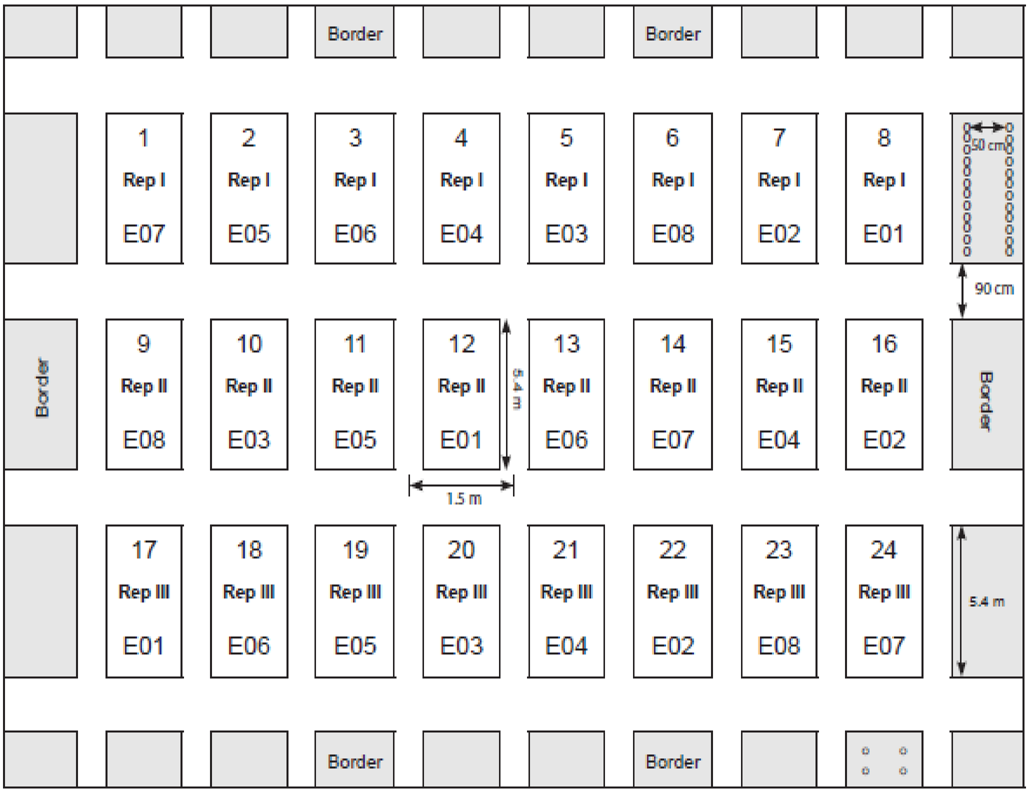

Figure. 1. *Sample field layout for 2-row planting (the border area can have one or two rows of chili pepper). The suggested distance between furrows is 1.5 m for 2-row planting or 1 m for 1-row planting.*

Harvesting

During the initial plant growth stage, pinch off the flower buds and/or small developing fruits at first and second nodes, and remove all emerging side branches before first node (place of bifurcation of main branch). Harvest the fruits when they have turned completely red, and yields should be recorded on a fresh weight basis. It usually takes 50–60 days after flowering for the first fruit to fully ripen. Chili pepper production can continue for several months under optimum conditions depending on genotypes and the environment, but the yield data for variety field trials can be recorded for only 10 weeks.

Data to collect

Researchers should keep a record of the basic characteristics of the trial site and the management practices employed when conducting a variety trial (Table 2). This information can be useful for explaining varietal performance in different environments. For 2-row planting, data are collected from 20 inner plants. For 1-row planting, data are collected from 10 inner plants. Plant characteristics and reactions to biotic stresses, yield and its components to be collected for each plot are as follows:

1. ***Days to 50% flowering:***
   Number of days after transplanting (DAT) to 50% anthesis (50% of plants in a plot have open flowers at the second node). Check plots three times a week and record data in Table 3.

2. ***Days to 50% maturity:***
   Number of days after transplanting (DAT) to 50% maturity (50% of plants in a plot have ripe fruits [usually red]). Check plots three times a week and record data in Table 3.

3. ***Biotic stress rating:***
   Evaluate incidence of diseases and insects when the first harvest is done. Record incidence as R (=resistant, 70-100% of plants per plot are healthy), MR (=moderate resistant, 50-70% of plants per plot are healthy), MS (=moderate susceptible, 20-50% of plants per plot are healthy) or S (=susceptible, 0-20% of plants per plot are healthy). Check figures 2-5 for the symptoms of virus, bacterial wilt, anthracnose and phytophthora blight; and figures 6-8 for insect damage symptoms to help you identify, score and record the severity of pests (Table 3). Other diseases or insect pests with high incidence should be recorded after proper diagnosis.

4. ***Number of plants harvested:***
   Count the plants harvested from the 2-row or 1-row plot. This will indicate population density and help explain low yields in plots with poor stands (Table 4).

5. ***Fresh fruit yield:***
   Separate the marketable (worth selling) from nonmarketable fruits (damaged due to biotic and abiotic stress or remarkably tiny fruits) after harvesting. Record weight of marketable and nonmarketable fruits from each plot and the harvest dates. Repeat the process for 10 weeks. The total marketable yield is obtained by adding the yields of individual harvests (Table 4).

   The yield per plot (kg/plot) can be converted into tonnes per hectare with the following formula:

$$\text{Yield (t/ha)} = \frac{\text{plot yield (kg) / 1,000 (kg/t)}}{\text{harvested area (m}^2\text{) / 10,000 (m}^2\text{/ha)}}$$

Example of 2-row planting (data collected from 20 inner plants):
plot yield: 30 kg
harvested area: 6.75 m^2 (=0.45 m x 10 plants x 1.5 m)

$$\text{Yield} = \frac{\text{30 (kg) / 1,000 (kg/t)}}{\text{6.75 (m}^2\text{) / 10,000 (m}^2\text{/ha)}} = \text{44.4 t/ha}$$

6. ***Fruit length, width and weight:***
   Average fruit length (cm), width (cm) and weight (grams) can be calculated from 10 randomly selected marketable fruits (fresh and red) in the second harvest (Table 4).

   Example:
   Weight of 20 marketable fruits = 120 g

$$\text{Average fruit weight} = \frac{120}{20} = 12\text{ g}$$

7. ***Remarks:***
   Any other interesting observations not recorded elsewhere that could help explain the outcome of the trial (Table 3).

Table 2. Sample data sheet for test location and crop management.

CHILI PEPPER VARIETY FIELD TRIALS: TEST LOCATION AND CROP MANAGEMENT DATA SHEET

Country ______________________________

Cooperator (s)/ data taker (s) ______________________________

E-mail: ______________________________

LOCATION DATA

Farm or experiment station ______________________________

State / province / department ______________________________

LATITUDE degrees minutes N or S ☐☐ ☐☐ ☐☐

LONGITUDE degrees minutes E or W ☐☐☐ ☐☐ ☐☐

ALTITUDE above sea level ☐☐☐☐m

SOIL

Previous crop

Surface texture ☐ sandy loam ☐ clay loam ☐ silty loam ☐ other

Surface pH ☐ >7 ☐ 6-7 ☐ <6 or actual value

CLIMATE DATA DURING TRIAL ☐Hot-wet ☐ Hot-dry ☐ Cool-dry ☐ Cool-wet ☐ Other

Average min. temp. ☐☐℃ Average max. temp. ☐☐℃ Total rainfall ☐☐☐☐mm

Remarks about deviations from normal ______________________________

EXPERIMENT DATA

PLOT DATA Plot width (m) Plot length (m) Spacing between rows (cm)

No. of plants/plot No. of rows/plot Plant spacing within row (cm)

SEEDLING MANAGEMENT ☐ bare root ☐ seedling tray ☐ other ______________

PLANTING SCHEDULE

date sown (day month year) ☐☐ ☐☐ ☐☐☐☐ date transplanted (day month year) ☐☐ ☐☐ ☐☐☐☐

HARVEST 1st ☐☐/☐☐ 2nd ☐☐/☐☐ 3rd ☐☐/☐☐ 4th ☐☐/☐☐ (day/month)

OTHER PRACTICES ☐ Mulching ☐ Staking ☐ Others, please specify ______________

BIOTIC STRESSES OBSERVED AND CONTROL

Diseases: ☐ virus ☐ bacterial wilt ☐ anthracnose ☐ Phytophthora blight ☐ others

Control methods: ☐ chemicals applied ☐ others

Pests: ☐ broad mite ☐ aphid ☐ thrips ☐ others

Control methods: ☐ chemicals applied ☐ others

In your opinion, considering yield, plant type, fruit acceptability to local consumers, and other factors, which are the four best chili pepper lines?

1 ______________________

2 ______________________

3 ______________________

4 ______________________

Table 3. Sample data sheet for plant characteristics and reactions to biotic stresses.

Plot no.	Rep	Entry code	Days to 50% flowering	Days to 50% maturity	Incidence of diseases and insects*								Remarks
					Virus	BW	AN	PB	BM	Aphid	Thrips	Others	
1	1	E07											
2	1	E05											
3	1	E06											
4	1	E04											
5	1	E03											
6	1	E08											
7	1	E02											
8	1	E01											
9	2	E08											
10	2	E03											
11	2	E05											
12	2	E01											
13	2	E06											
14	2	E07											
15	2	E04											
16	2	E02											
17	3	E01											
18	3	E06											
19	3	E05											
20	3	E03											
21	3	E04											
22	3	E02											
23	3	E08											
24	3	E07											

* BW (= bacterial wilt), AN (= anthracnose), PB (= Phytophthora blight), BM (= broad mite)
Rate the plants when the first harvest is done at one of four levels:
R (=resistant, 70-100% healthy plants/plot)
MR (=moderate resistant, 50-70% healthy plants/plot)
MS (=moderate susceptible, 20-50% healthy plants/plot)
S (=susceptible, 0-20% healthy plants/plot)

5

Table 4. Sample data sheet to track yield and yield components.

Plot no.	Rep	Entry code	No of plants harvested	Average fruit			Fruit yield (kg/plot)								Total M[2] wt. (kg)
				L[1] (cm)	Wd[1] (cm)	Wt.[1] (g)	1st harvest ( )		2nd harvest ( )		3rd harvest ( )		4th harvest ( )		
							M[2]	NM[2]	M[2]	NM[2]	M[2]	NM[2]	M[2]	NM[2]	
1	1	E07													
2	1	E05													
3	1	E06													
4	1	E04													
5	1	E03													
6	1	E08													
7	1	E02													
8	1	E01													
9	2	E08													
10	2	E03													
11	2	E05													
12	2	E01													
13	2	E06													
14	2	E07													
15	2	E04													
16	2	E02													
17	3	E01													
18	3	E06													
19	3	E05													
20	3	E03													
21	3	E04													
22	3	E02													
23	3	E08													
24	3	E07													

( ) indicate the date of harvest.
Add more rows if there are more than 8 entries. Add more columns if there are more than 4 harvests.
[1] L: length; Wd: width; Wt.: weight
[2] M: marketable fruits; NM: nonmarketable fruits

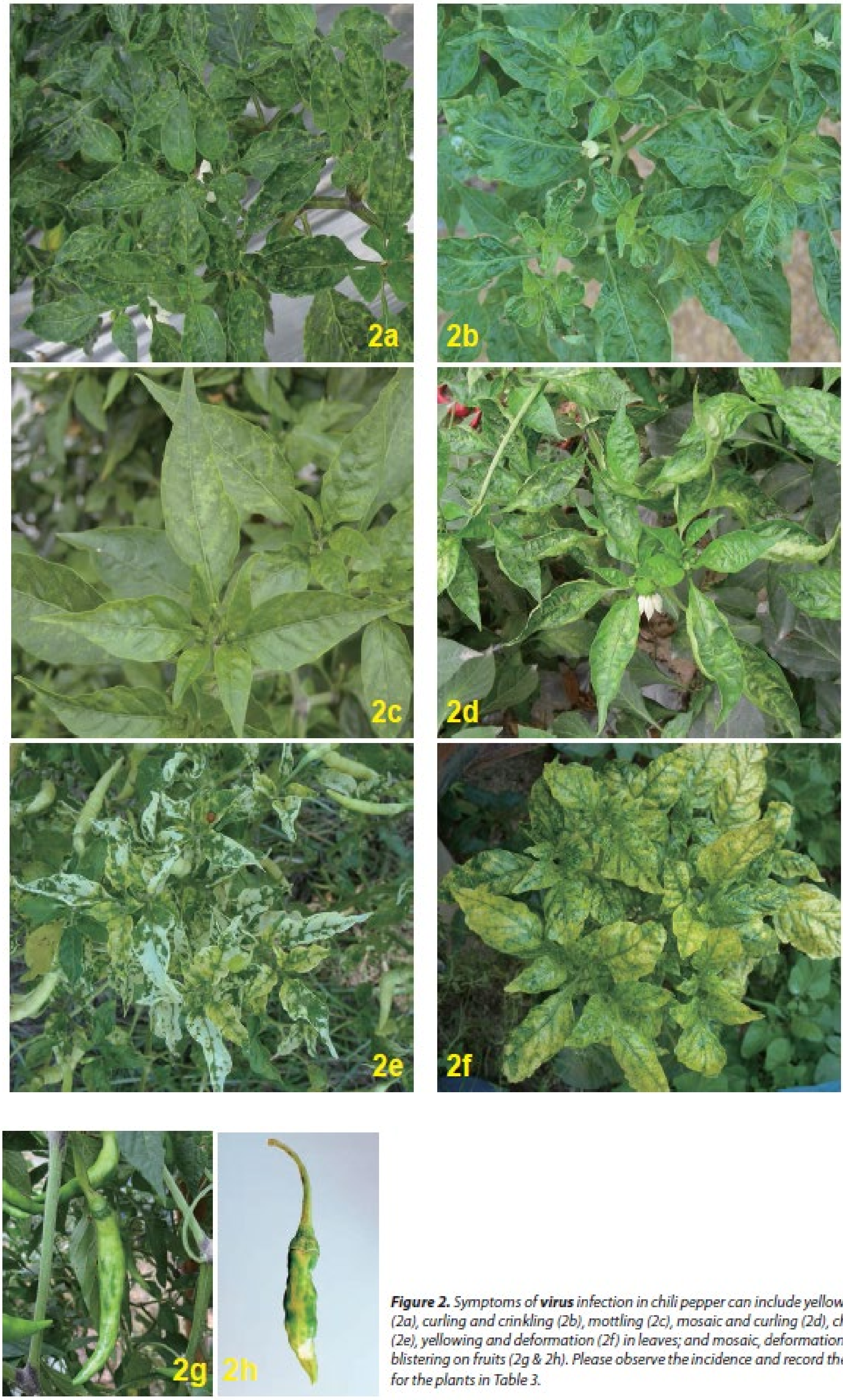

*Figure 2. Symptoms of **virus** infection in chili pepper can include yellow spots (2a), curling and crinkling (2b), mottling (2c), mosaic and curling (2d), chlorosis (2e), yellowing and deformation (2f) in leaves; and mosaic, deformation and blistering on fruits (2g & 2h). Please observe the incidence and record the rating for the plants in Table 3.*

Figure 3. *Typical symptoms of* **bacterial wilt** *(BW) first appear as drooping of a few young leaves. A sudden complete wilt soon follows. Infected plants display wilting with little or no yellowing leaves (3a). The disease can be correctly diagnosed by observing bacterial streaming from vascular system in the lower stem using a stem-ooze test (3b). Please observe the incidence and record the rating for the plants in Table 3.*

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Figure 4. *Typical symptoms of* **anthracnose** *(AN) for chili pepper are usually on fruits at both immature (4a) and mature (4b) stage. The symptoms initially begin as water-soaked lesions that become sunken and tan. The lesions expand soon and eventually produce gelatinous, salmon-colored conidia spores. Concentric rings of the acervuli are common within the lesion. In some cases, the lesions are dark due to the formation of numerous black setae or other fungal tissue. Please observe the incidence and record the rating for the plants in Table 3.*

Figure 5. *The first symptom of* ***Phytophthora blight*** *(PB) on chili pepper in the field is commonly crown rot (5a). Root infection (5c) causes rapid collapse and death of the plant (5d). Following rainstorms, some typical symptoms such as water-soaked lesions on leaves and fruits, and brown to dark purplish lesion on upper stem can be found (5b). All plant parts including roots, crowns, stems, leaves, and fruit at any growth stage can be attacked. The wilting symptom is similar to bacterial wilt if no foliar infection occurs. However, no bacterial streaming can be found using a stem-ooze test. Please observe the incidence and record the rating for the plants in Table 3.*

Figure 6. *The symptoms of* ***aphid*** *damaged chili pepper plants include leaf distortion and mottling; chlorotic leaf spots and black sooty mold. Please observe the incidence and record the rating for the plants in Table 3.*

Figure 7. The symptoms of **broad mite** damaged plants include leaves curling downwards (7a & 7b); growing point and young leaves are bronzed and stunted; necrosis on the growing point and dropping of old leaves; and cork-like fruits. Please observe the incidence and record the rating for the plants in Table 3.

10

Figure 8. The symptoms of **thrips** damaged plants include young leaves curling upwards (8a & 8b); fruits netted with cork-like streaks; plants stunted with small leaves on young shoots. Please observe the incidence and record the rating for the plants in Table 3.

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The Excel format data sheets are available online at
http://avrdc.org/seed/improved-lines/chili-pepper/#.VDNhUvmSxz4

10/2014

11.7 Appendix 7: Fiji Farmer Survey Report

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SPC
Secretariat of the Pacific Community

Research in Action 7

Vegetable production, postharvest handling and marketing in Fiji

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Vegetable production, postharvest handling and marketing in Fiji

November 2013

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AVRDC
The World Vegetable Center

AVRDC – The World Vegetable Center is an international nonprofit research institute committed to alleviating poverty and malnutrition in the developing world through the increased production and consumption of nutritious, health-promoting vegetables.

About *Research in Action*

The *Research in Action* series disseminates the practical applications of the Center's work in vegetable breeding, production, marketing, and nutrition. The series aims to encourage vegetable-based enterprise through the extension of information, ideas, technologies, and skills.

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We would like to acknowledge the support of the Fiji Ministry of Agriculture, Forestry and Fisheries, who greatly facilitated us in conducting the survey. We thank the Australian Centre for International Agricultural Research (ACIAR) for their financial support of the work. Last but not least, we thank all of the farmers that took part in the survey for giving their valuable time to respond to our questions.

Executive summary

This analysis provides the results of a survey conducted with 80 vegetable farmers in Fiji's Sigatoka Valley, Cane Coastal Area, and Koronivia on Viti Levu. The objective of the survey was to understand the current practices of vegetable farmers and the constraints they face. These observations will be used to inform the implementation of two projects funded by the Australian Centre for International Agricultural Research and implemented by the Secretariat of the Pacific Community, University of Queensland, University of Sunshine Coast, and AVRDC – World Vegetable Center in partnership with the Fiji Ministry of Agriculture, Forestry and Fisheries. The projects aim to increase the production of high-value vegetables, in particular to supply hotels, resorts and supermarkets. This is seen as a priority for economic development in Fiji by the government as it will support sustainable livelihoods for farmers.

Key findings of the survey showed that:

- Most vegetable farmers in Fiji were smallholders (1-5 acres) that relied on family labor.
- The average income of vegetable farmers was in line with the national average income of rural households.
- The most common vegetables grown were tomato, eggplant and English cabbage.
- Only 10% of farmers sold produce to supermarkets, resorts or export markets.
- Most farmers sold their produce in large domestic markets in Suva, Nadi and Sigatoka keeping approximately 10% of their harvest for personal consumption.
- Only 12% of farmers sold through a vendor with most using a middleman or selling produce directly themselves.
- Market prices of vegetables are highly linked to supply in domestic markets with prices dipping during periods of high supply. This corresponds with the cool dry season in Fiji (August/September).

The survey also highlighted some key constraints. These constraints are mainly related to vegetable production rather than postharvest handling or marketing but the low level of farmers engaged in supplying resorts and supermarkets suggests they faced considerable challenges.

The key constraints include:

- *Fertilizer use is high but not sufficient.* A study on soil health in the vegetable production areas of Fiji revealed that nutrient availability and organic matters should be increased. Currently fertilizer use is limited to the application of NPK and Urea. Greater use of composts and manures could increase vegetable productivity.

- *Overuse or misuse of pesticides.* Nearly all farmers used one or more synthetic pesticides. It appears that common practice was to apply pesticide on a weekly or fortnightly basis rather than in response to visible pest damage or pests on the crop. Knowledge of the particular pests attacking crops or the appropriate pesticide for control also appeared to be low. This suggests there may be overuse or misuse of pesticides. Farmers identified pest damage as the greatest constraint to production.

- *Negative impacts of flooding.* Nearly all of the farmers (91% of respondents) were negatively affected by flooding but only a handful had taken any measures to guard against it, such as the installation of improved drainage systems. With expected increases in the intensity of rainfall in the coming years from climate change this is likely to become an increasing challenge.

- *Wastage in harvesting and postharvest handling of tomatoes.* Tomatoes are often harvested while they're still green (as opposed to beginning to turn red) and then ripened using the sun on the farm. Evidence from another study suggests that the high temperatures and differing rates of ripening means that approximately 19% of the harvest either fails to ripen or rots before being transported.

These findings suggest that emphasizing soil fertility and integrated pest management in extension work would support greater intensification of vegetable production. Pest management issues beyond the use of pesticides (e.g. crop rotation and identification of pests and diseases) in particular appear to be an area for intervention. For longer term support to vegetable production there is a need for more widespread installation of measures to reduce the negative impact of flooding. Work on postharvest handling of tomatoes is clearly justified.

There is also a need for further investigation into the practices of larger farms. In general, respondents with larger farms did not follow production practices commonly used by commercial farms. For example, they did not use a greater amount of permanent or contract workers, they predominantly served local markets rather than hotels, and they tended to sell their produce directly as opposed to using a middleman. The results could have been skewed since the number of respondents with farms greater than 10 acres was low (11% of respondents). Nevertheless, given the importance of commercial farms for the intensification of horticultural production in Fiji, this anomaly deserves further investigation.

Introduction

The development of high-value crops for domestic consumption and export is seen as a priority for economic development and improved livelihoods in many Pacific island countries. The Fiji Ministry of Agriculture, Forestry and Fisheries (MAFF)[1] identified fruits and vegetables as among the six "priority concerns" for export promotion and import substitution. The government has identified cabbages, lettuce, tomatoes, capsicums, carrots, onions, potatoes, and peas as target crops for greater production. Hotels, supermarkets and restaurants are seen as key domestic markets.

In response, the Australian Centre for International Agricultural Research (ACIAR) launched two projects[2] in 2012 to support sustainable intensification of high-value vegetable production in Fiji. MAFF, Secretariat of the Pacific Community (SPC), University of Queensland (UQ), University of Sunshine Coast and AVRDC – The World Vegetable Center (AVRDC) are partners in the projects.

Understanding current practices and perceptions of vegetable farmers in production, postharvest handling and marketing enables the project team to design interventions to address constraints to expanding vegetable production and trade. Thus, one of the first activities of the two projects was to conduct a survey in project target areas to collect the information. The findings presented in this situational analysis are based on that survey.

The project target areas include the Sigatoka valley, Cane Coastal Area, and Koronivia of Viti Levu. The Sigatoka valley is the main vegetable production area in Fiji. It is estimated that around 80% of the total vegetable production occurs in the valley. The Cane Coastal Area and Koronivia were selected due to the presence of markets and communities willing to join the project participatory guarantee system activity[3]. These are the areas where the projects will conduct most of their activities.

Survey methodology

Villages where vegetable production is a main activity were selected from the Sigatoka valley, Cane Coastal Area, and Koronivia on Viti Levu (Annex 1). The survey targeted existing farmer groups in these villages. The group leader was notified prior to the interviews. The leader then invited the group members to participate in the survey.

In total, 80 households were surveyed. The survey was conducted in the following villages: Nawamagi, Lokia and Nabitu in the Sigatoka East Bank; Raunitoga in the Sigatoka Mid-Valley; Qereqere and Barara in the Sigatoka Lower Valley; Biausevu, Komave and Namatakula in the Cane Coastal Area; and, Koronivia Road in Koronivia.

A structured questionnaire divided into the following sections was used to collect data: a) tracking information, b) socio-demographic information, c) farm information, d) production information, e) market information, f) capital and socioeconomic status, and g) training and extension needs. Production information was collected for up to three of the most important vegetable crops on each farm.

The survey team consisted of four enumerators (SPC and AVRDC staff: Suzanne Neave, Govind Raju, Nitesh Nand, Aloesi Hickes). They were assisted by MAFF staff (Makereta Rasuka, Ajay Chand, Sakeasi Ralulu, Unaisi

[1] MAFF was the Ministry of Primary Industry at the time of the project.
[2] PC/2010/090 "Strengthening integrated crop management research in the Pacific Islands in support of sustainable intensification of high-value crop production" and PARDI/2011.03 "Developing an integrated participatory guarantee system in the Pacific Islands in support of sustainable production of high-value vegetable crops"
[3] The Participatory Guarantee System is the focus of the second project PARDI/2001/03.

Remudu). Each household was visited by a three-person team (two enumerators and one MAFF staff). Prior to undertaking the household survey a training session was conducted by Suzanne Neave at the Sigatoka Research Station on August 27, 2012. During this session, the survey team went through the questions and clarifications were made. A trial run was also made with farmers who visited the research station on that day. The survey was conducted from September 5 to October 3, 2012.

Data constraints

Due to challenges in data collection and interpretation, some questions in the survey could not be analyzed. Annex 3 provides a detailed breakdown of the responses for each of the questions which provided usable data.

In interpreting the results attention should be paid to the difference between the percentage of 'respondents' and the percentage of 'responses'. For many questions in the survey, the respondents were able to give multiple answers. This means that sometimes answers are presented as a percentage of all of the answers provided, i.e. the percentage of responses. This is useful for identifying the most common answers but cannot be used to determine how many of the respondents gave that answer. For example, if 50% of responses were a certain answer this does not mean 50% of the respondents gave this answer. Care has been taken to indicate whether the result is a percentage of responses or respondents. Annex 3 also states the number of respondents and responses for each question.

Findings

This section outlines some of the key findings from the survey conducted in Fiji. The presentation of the findings roughly follows the different sections of the original questionnaire. These findings have been supplemented where possible by other studies and publications.

Farmer characteristics

The survey was conducted with 80 farmers from the Sigatoka valley, Cane Coastal Area and Koronivia with the greatest number of respondents (40%) located in the Sigatoka East Bank (see Table 1). Seventy-one percent of the respondents were 41 years old or more and they were almost exclusively male (94%).

The level of education of the respondents is broadly in line with the national average. Nearly all had at least attended primary school and 40% had gone on to attend secondary school, although only 8% completed it. The ethnicity of the respondents was approximately half Indo-Fijian (55%) and half i-Taukei (45%).[4]

Most respondents (76%) farmed in just one location, although 19 (24%) reported farming in two or more locations. Most respondents (58%) were also part of an organized agricultural group for production and marketing.

An annual income between $5,000 and $15,000 was reported by 49% of respondents. This is roughly in line with the national average. The average income of a rural household in Fiji in 2008/9 was around $11,600.[5] It was, however, difficult to know if most of the farmers were at the top or bottom of this fairly broad income range. Overall, 40% of respondents reported an income below the group average, i.e. below $5,001-$15,000, and only 3% reported an income higher than the average (see Annex 3)[6].

Table 1 breaks down some of this information according to the location of respondents. It shows that respondents in most areas reported an income range of $5,001-$15,001 except for respondents in the Cane **Coastal Area, who most commonly stated annual income as between $1,001-$5,000. The average number of**

[4] I-Taukei is used to indicate indigenous Fijians.
[5] Fiji Bureau of Statistics, Household Income and Expenditure, June 2012.
[6] Other answers included, 'don't know' and 'prefer not to say'.

people per household in the Cane Coastal Area was also higher than the other areas. This does not mean, however, that in general incomes are lower in the Cane Coastal Area. The high standard deviation for the number of people in the households suggests that these results are being driven by a couple of extreme results.

Table 1: Key farmer characteristics by location

Location	% of respondents	Average no. in household	Standard deviation of no.in household	Average income bracket
Sigatoka (lower valley)	24%	3.9	2.5	$5,001-$15,000
Sigatoka (middle valley)	18%	3.9	1	$5,001-$15,000
Sigatoka (east bank)	40%	4.5	1.8	$5,001-$15,000
Cane Coastal Area	13%	6.8	4.2	$1,001-$5,000
Koronivia	6%	5.2	0.8	$5,001-$15,000

Vegetable production is the main source of income for 71% of respondents. This indicates that the targeting of the survey on key vegetable growing areas was successful. Other sources of income included growing fruit and root crops, and raising livestock.

Farm information

Land used for vegetable production

The size of farms of the respondents ranged from half an acre up to 27, acres although 5.8 acres was the average. This indicates that the majority of respondents are smallholder farmers. The area of land used for vegetable production also varies widely but mainly falls between three and four acres (Fig. 1). Overall, the average amount of land used for vegetable production was about two thirds of total farm size (Table 2).

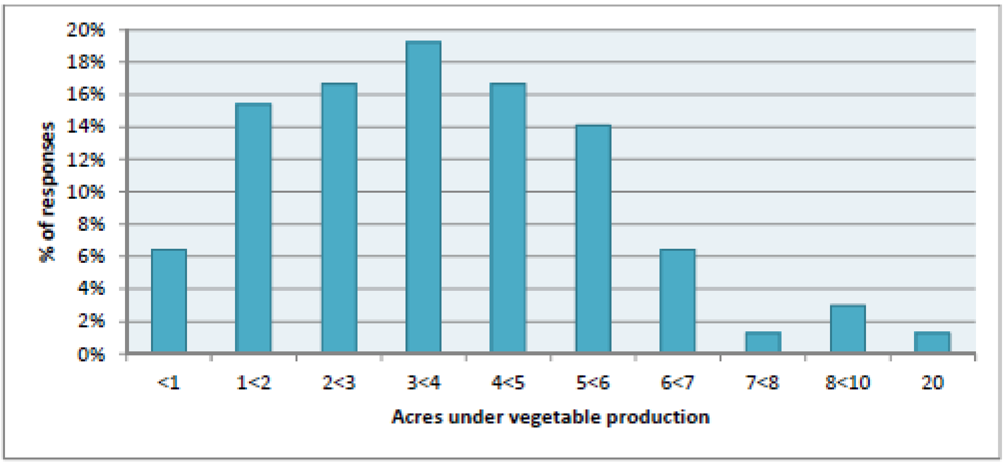

Figure 1: Area of land used for vegetable production (% of responses)

Table 2 shows that the average percentage of land used for vegetable production is highest on small farms between one and five acres. Variability in the use of land for vegetable production increased with the size of farms. This is shown by the high standard deviation for average land used for vegetables when farm size is between 20-30 acres. For example, one farmer had 10 acres of land but used only 0.3 acres of it for vegetable

production, whereas another had a farm of 27 acres and used 20 acres for vegetable production[7]. Vegetable production may be preferred by farmers with smaller landholdings because it provides relatively quick income whereas farmers with larger landholdings are able to diversify into longer term crops such as fruit trees or root crops.

Table 2: Farm size and area of land under vegetable production

Area of farm (acres)	**% of responses**	**Average farm size (acres)**	**Standard deviation of farm size**	**Average land for vegetables (acres)**	**Standard deviation of land for vegetables**	**Average % of land used for vegetables**
<1	**4%**	**0.57**	**0.06**	**0.23**	**0.05**	**42%**
1<5	**46%**	**3.32**	**0.92**	**2.55**	**1.11**	**77%**
5<10	38%	6.48	1.43	4.07	1.57	64%
10<15	6%	11.80	2.95	4.75	2.95	40%
15<20	3%	15.50	0.50	5.00	4.00	31%
20<30	3%	24.50	2.50	13.00	7.00	51%
Total	100%	5.83	4.39	3.52	2.67	66%

Land tenure

Land tenure for agriculture in Fiji consists of freehold land, crown land and native land. Native land is a customary land tenure system and refers to land which is communally owned by the i-Taukei.[8] Native land can be used for agriculture by the original Mataqali owner-occupants ('Mataqali land') or can be leased to other farmer occupants through the Native Land Trust Board ('NLTB land'). According to the 2009 Agricultural Census, 66% of agricultural land in Fiji was either Mataqali (35%) or NLTB land (31%).[9]

The most common form of land tenure for the respondents of the survey was Mataqali land (41% of respondents). Other common forms were freehold (25%) and NLTB leases (20%)[10]. Farmers with freehold land have a slightly higher average size of farm than farmers under other systems.[11]

Main crops

Farmers were asked to name their three main crops. Answers included more than 18 different crops although **tomatoes, eggplants and English cabbage[12] were by far the most common (Fig. 2).**

[7] The respondents with large farms who used a low percentage of it for vegetable production tended to grow root crops.
[8] Department of Lands and Surveys, Land Tenure Systems in Fiji.
[9] Fiji National Agricultural Census, 2009, Department of Agriculture, Economic Planning and Statistics Division.
[10] The remaining answers were mainly sharecropping or combinations of sharecropping with Mataqali, NLTB or freehold.
[11] Average farm size for freehold land is 7 acres, in comparison to 6 acres for NLTB leases, 4 acres for sharecropping and 5 acres for Mataqali.
[12] This terminology is used in Fiji to distinguish between Chinese cabbage (otherwise known as bok choy or pak choi)

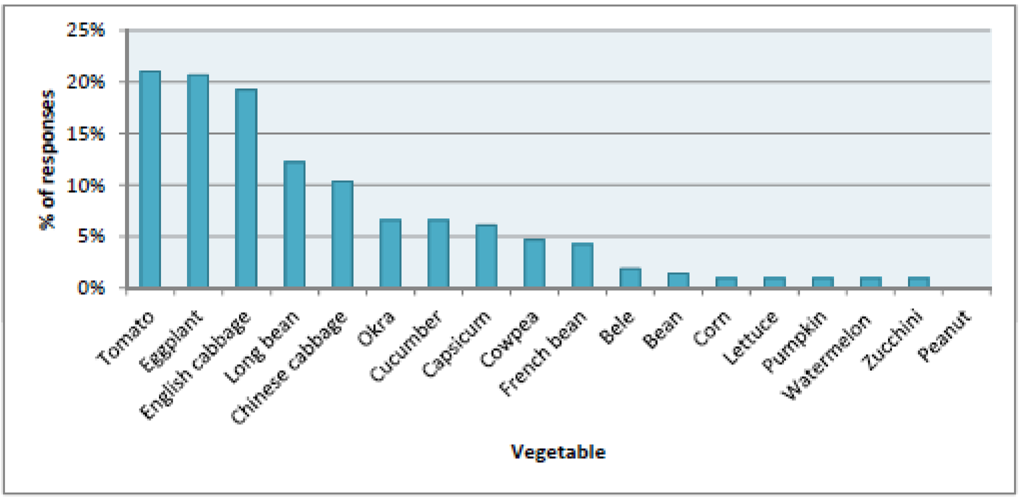

Figure 2: Main crops under production (% of responses)

Respondents were also asked to estimate the amount of land used for different vegetables (Fig. 3). Tomatoes, eggplant and English cabbage are still the top three crops under production. Although a greater number of farmers are growing eggplant, the area of land used for eggplant production is actually lower than that of English cabbage.

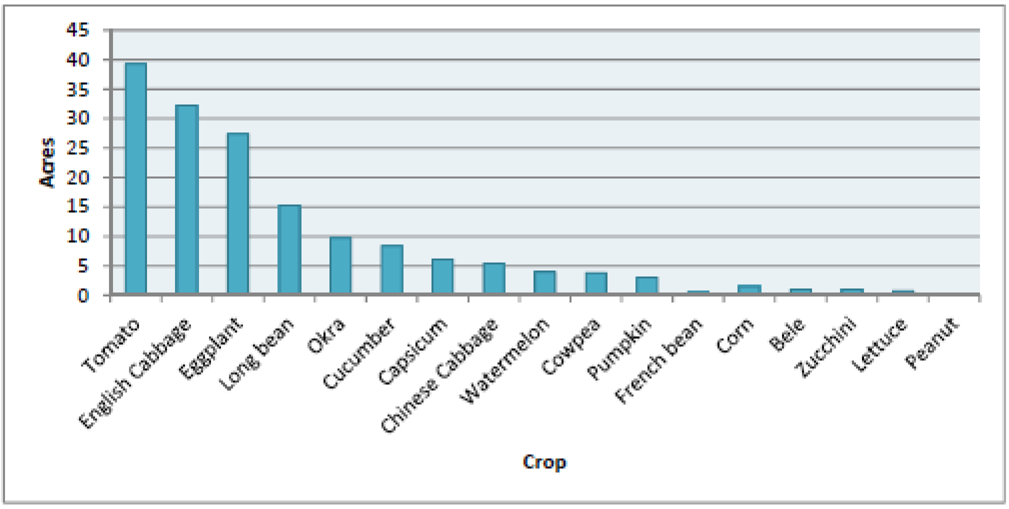

Figure 3: Area of land under production (acres per crop)

Rotations and seasons

The peak season for vegetable production is around August/September. In Fiji the hot months are December to April; humidity and rainfall are also high in these months. The cool season is from May to November. Consequently, vegetable production peaks around the mid-point of the dry cool season. Annex 2 provides temperature and rainfall information for key locations on Viti Levu.

Most respondents do not change crop varieties for the different seasons but they do tend to rotate the type of crop grown. Sixty-five percent of responses revealed rotations between two or more kinds of vegetables and 25% of the responses reported rotation between vegetables and cereals such as maize. Rotation is a good

practice to avoid build-up of soil-borne disease; this is particularly important for smallholders who have limited land area and are more likely to monocrop.

Leaving land fallow appears to be an uncommon practice, with 64% of responses reporting never leaving the land fallow. Only 12% of responses revealed fallow periods before and after vegetable production. Such intensive land use is likely to have negative impacts on soil fertility and to lead to land degradation.

Land characteristics

The majority of respondents (85% of responses) reported farming on flat land. No farmers reported vegetable production on land with a slope of 15° or more. Some care should be taken with this result, since national guidelines discourage farming on land which slopes 15° or more. In fact, it is often included in lease agreements between landowners and tenants with the NLTB and the Land Use Department of the MAFF. Consequently, respondents may have been unwilling to reveal practices that went against the recognised guidelines. The region as a whole is known to be suffering from high levels of land degradation. This is due in part to intensive cultivation of sloping land[13], mainly attributed to the intensification of sugar cane production rather than vegetables.

The finding on the slope of the land is consistent with subsequent findings regarding flooding. When asked about events affecting their farm in the last 5 years, 91% of the respondents reported experiencing floods. The most cited years of flooding events were 2012 and 2009, which correspond with the dates of the largest floods experienced on Viti Levu in recent years. The 2009 flood was one of the worst floods experienced since 1931, with western Viti Levu being one of the worst affected areas. Heavy rainfall was experienced for more than a week and most low lying areas were underwater for days; some places experienced flood levels of up to 3-5 meters[14]. Since horticultural crops are typically planted on low-lying land, the floods had a hugely detrimental impact on vegetable production. Most of the farmers surveyed were located near the Sigatoka River, which is prone to flooding and explains their high exposure.

Climate change projections for Fiji predict increased intensity and frequency of extreme rainfall with high confidence[15]. This means that challenges caused by flooding are likely to increase. Interestingly, only 10 farmers reported the installation of improved drainage systems despite the high level of flooding experienced.

A subsequent study on soil health was conducted by AVRDC and MAFF in the vegetable growing areas considered in this analysis. The study looked at 11 different measures of soil health for 15 locations in the Sigatoka valley, Cane Coastal Area and Koronivia. The findings showed that all of the farms had 'moderate' soil health, which means that on average measures such as texture, microbial activity, pH values etc. were in the middle of the range from poor to good. The main concerns were low soil fertility and low levels of organic matter in the soil. The study recommended that farmers add organic matter to the soil, rotate crops and use cover crops to help increase the fertility of the soil.

Land preparation

Overall, farming is done by hand, sometimes with animal traction (56% of responses). A significant number of respondents reported combining animal traction with the use of a tractor but only a handful (4 respondents) use a tractor without hand or animal traction.[16] There were few obvious commonalities amongst the respondents who do use only tractors: the size of their farms ranged from 2 to 22 acres and they were located in different areas.

[13] Identified direct causes of land degradation in Fiji as described in the 2007 'National Action Plan to Combat Desertification/Land Degradation and to Mitigate against Drought', included intensive sloping land cultivation.

[14] 'Economic Costs of the 2009 Floods in the Fiji Sugar Belt and Policy Implications', Padma Lal, Rashmi Rita and Neehal Khatri, 2009.

[15] Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports, Fiji, p. 87.

[16] Surprisingly, only one of the respondents who reported only using tractors had a farm larger than 9 acres. They also all had a range of incomes and dependence on vegetable production for income.

The most common form of land preparation was the use of an animal and a disc plough or harrow. Farmers reported a wide range of depth for tillage, but 38% of responses were at a depth between 11-15 centimetres. Tilling the land is mainly done just before planting. The majority of the time crop residue is ploughed back into the soil, although 40% of responses indicated residues were removed from the field.

Roles and responsibilities

The number of people working on the farms ranged from one person to six but the most common answer (42% of respondents) was that just two people worked on the farm. There appears to be some correlation between farm size and the reported number of workers on the farm (Table 3) although perhaps the relationship is not as strong as might be expected.

Table 3: Average number of workers by farm size

Area of farm (acres)	Average number of workers
<1	2.7
1<5	2.6
5<10	3
10<15	3.2
15<20	2.5
20<30	4.5

Respondents were asked about the type of labor used for different tasks. The different types included family labor, casual labor, contract and permanent staff. Overall, family labor was used for nearly all tasks. This is particularly true for the purchasing of inputs, selling produce, and administration, which was reported as almost exclusively done by family workers. Only nine farmers reported using permanent or contract workers. Casual laborers were used, often in combination with family workers, particularly for weeding, planting, ploughing and harvesting. Larger farms more commonly reported using family labor alongside casual labor but there was no strong trend amongst the larger farms to use more contract or permanent labor.

Respondents were also asked about the breakdown of tasks between men and women. Figure 4 shows the reported work division between male and female household members for different tasks in crop production. Some care should be taken in interpreting these results as 94% of the respondents were male. If a higher number of women had been included in the survey we might have found a different result.[17] However, it appears there are clear gender differences in farm work, with men doing tasks such as ploughing, input application and transport and women playing a greater role in tasks such as weeding, planting and harvesting.

[17] In future studies of this kind greater attention should be paid to ensuring women's input into questions around roles and responsibilities, to prevent bias in the responses.

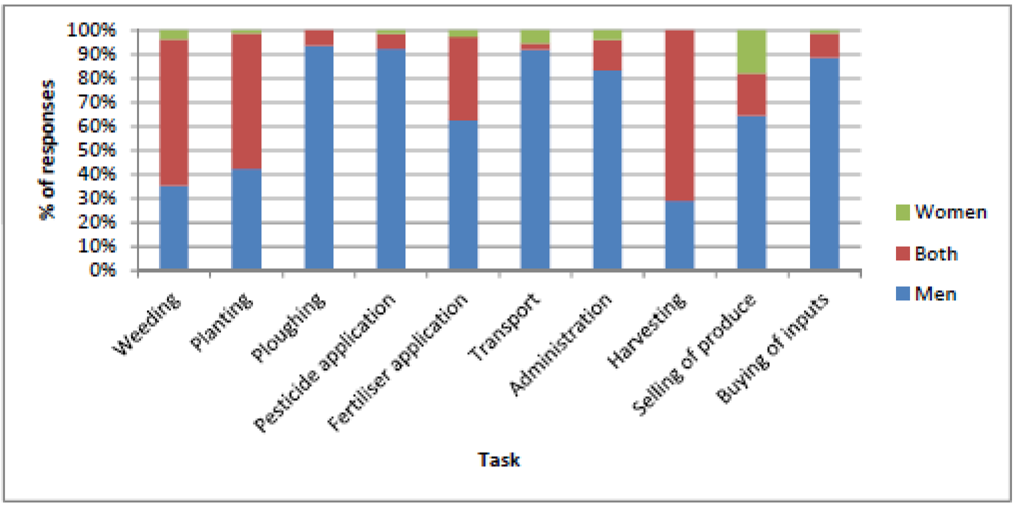

Figure 4: Roles and responsibilities for crop production between men and women (% of responses per task)

Production of main crops

The following sections on production and postharvest handling focus on the results for the three main crops identified in the previous section, namely, tomatoes, eggplant and English cabbage. As capsicum is one of the crops targeted for export promotion and import substitution, analysis of capsicum has also been included where possible[18].

Care should be taken when drawing conclusions from the results in this section. Analysis at the level of individual crops considerably cuts down the number of responses for each answer. A smaller number of responses mean that extreme or uncommon responses have greater potential to unduly influence the results, potentially making them less representative of common practices.

Seedlings

The majority (84%) of farmers grew their own tomato, eggplant and English cabbage seedlings. Farmers who did not grow their own seedlings tended[19] to source them from MAFF or the Taiwan Technical Mission. Farmers who reported growing their own seedlings typically created seedbeds in their fields. Most (52%) farmers growing their own seedlings did not use any additional fertilizer for the seedbed. Thirty-four percent reported mixing NPK into the soil for the seedbed. The remaining farmers used either a combination of NPK and manure or compost, or used special potting mixes. An analysis of the quantities used for the mixes is unfortunately not possible[20] but it did appear there was some consensus on a quantity of between 30-50 g of NPK applied per square meter of soil.

Fertilizers

Fertilizer use is extremely common. All but two of the tomato, eggplant and English cabbage farmers report using some type of fertilizer. The most commonly used fertilizers are NPK (13:13:21) and Urea (Fig. 5).

[18] Only 10 respondents mention capsicum as one of their main crops, so in some cases the sample size was too low to analyze. Capsicum is included wherever it is suitable to do so with appropriate caveats.
[19] Six of the 13 farmers who said they did not grow their own seedlings gave details of where they got them from.
[20] The data on the quantity used did not systematically give the amount of soil, or area of ground that was mixed with the fertilizer.

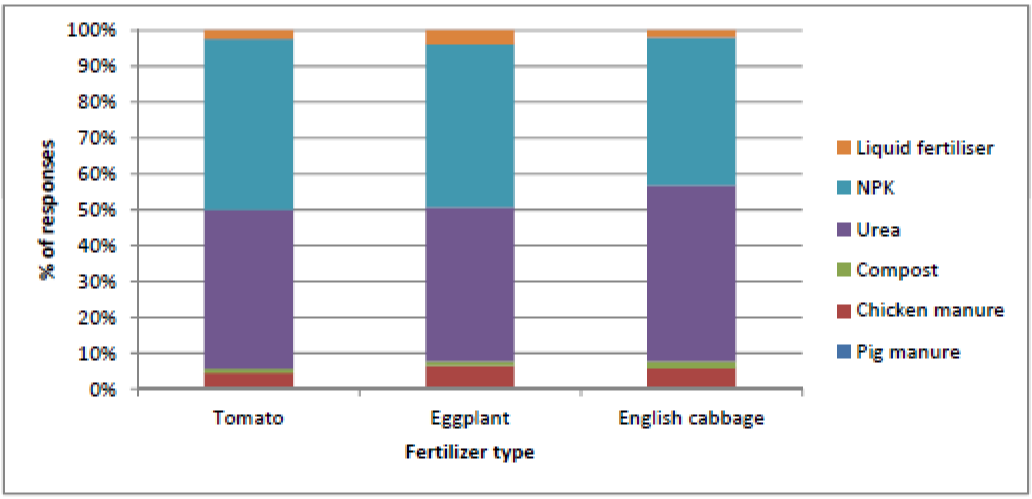

Figure 5: Fertilizer usage (% of responses per crop)[21]

NPK and Urea are most commonly applied together sometimes with another fertilizer such as chicken manure or liquid fertilizer but normally without. Table 4 shows that for tomatoes, eggplant and English cabbage the most common combination of fertilizer treatments is NPK with Urea. Only three respondents reported using another kind of fertilizer (in this case manure) without either NPK or Urea. Given the findings on soil health in the project area (see section on land characteristics) greater use of compost and manure would increase organic matter in the soil and be beneficial for soil fertility and vegetable production.

NPK is normally applied once or twice. If applied twice it tends to be first applied at planting and then again after three or four weeks or just before the vegetable flowers. If applied once it is typically done at flowering. Urea is typically applied just once, with NPK at planting.[22]

Table 4: Usage of Fertilizer combinations (% of responses per crop)

Combination	Tomatoes	Eggplant	English Cabbage
NPK& Urea only	70%	59%	65%
NPK & Urea & other	11%	7%	15%
Nothing	2%	2%	0%
NPK or Urea alone	7%	17%	15%
Other combination	9%	15%	4%

Pesticides and pest control

Nearly all (93% of responses) farmers reported using some form of commercial pesticide. There was, however, much greater variation on which pesticides are used, in comparison to fertilizers, even among farmers of the same crop.

Tomatoes

For tomato farmers, the most commonly cited pests (43% of responses) were caterpillars. Other pests included whitefly, cut worm and aphids. The most commonly used pesticide was Superguard but there was a broad range of answers (Table 5) and Prevathon, Crop guard and Suncis were also commonly used. Thirty percent of farmers who used pesticides used more than one type.

[21] Please note that since combinations of fertilizers are used, this demonstrates the popularity of the different answers.

[22] Data was also collected on the rate of application but the huge variation in answers suggests there was a problem with the original data.

The frequency of pesticide application is high. Fifty-three percent of all of the responses indicated application of pesticides fortnightly, 11% for weekly application. Only 15% of responses reported applying pesticide in response to seeing pest damage or pest larvae on the plants.

Table 5: Usage of pesticides (% of responses per crop - top 5)

Tomato		Eggplant		English cabbage	
Pesticide	% of responses	Pesticide	% of responses	Pesticide	% of responses
Superguard	15%	Confidor	20%	Prevathon	47%
Prevathon	10%	Suncloprid	19%	Steward	21%
Crop guard	10%	Superguard	15%	Multiguard	8%
Suncis	8%	Chloroprid	9%	Crop guard	5%
Crop control	8%	Orthene	8%	Suncloprid	3%

Eggplant

For eggplant, the most identified pest was thrips and thrips in combination with mites or caterpillars. The most popular pesticides were Confidor and Suncloprid, although again there were a number of different pesticides reported.

Frequency of pesticide application for eggplant appears to be even higher. The most common response was a weekly application of pesticide (34% of responses) with weekly or fortnightly application making up 62% of all responses.

English cabbage

All English cabbage farmers reported using some form of commercial pesticide. Forty-six percent used more than one, with Prevathon being the most popular. The most common identified pest was caterpillars (42% of responses) however a large number of respondents were unable to identify particular pests. Many responses were noted the pesticide used was against 'insects' 'any worms' or 'unknown'.

A large number of farmers were unable to identify the particular pests that attacked their crops, but tended to use broad spectrum pesticides against unnamed insects, mites and bugs. One caveat to this statement is that, in the experience of SPC staff, commercial and semi-commercial farmers are very familiar with the pests that they deal with (as they deal with them year after year); instead, their struggle is to identify appropriate pesticides.

As with tomatoes and eggplant the frequency of pesticide application is high. Seventy-five percent of responses revealed a weekly or fortnightly application of pesticide. Only 15% of responses reported applying pesticide based on observations of pest damage, and only one farmer said it was in response to the stage of development of the plant.

Capsicum

There were only 10 capsicum farmers, so it was not possible to draw out any particular trends although the responses that were given are in line with those for tomatoes, eggplant and English cabbage.

Pest management

Information was gathered from respondents regarding the quantity of pesticide applied, cost of pesticide and time taken for application. Unfortunately, due to challenges in data collection, it is not possible to provide the results here. However, the concentrations of pesticide used do, upon initial inspection, provide a surprisingly low level of consistency even when looking at the same pesticide used on the same pests.

The most likely conclusion from these results is that pesticide is generally not applied in response to observation of a particular pest or at a particular stage of crop development. It appears that most farmers use

pesticides on a weekly or fortnightly basis regardless of the pest load on the crop. Interestingly, when asked explicitly how they make pest management decisions, the majority of respondents cited answers such as 'when damage is seen on the crop' or 'crop monitoring' (Fig. 6). This appears to be a direct contradiction of the previous answers.

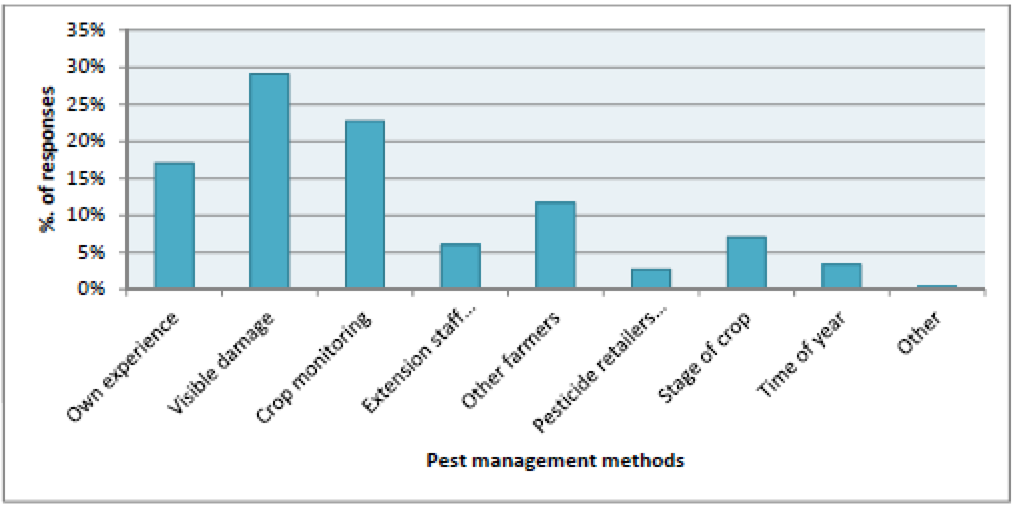

Figure 6: Influences for pest management (% of responses)

Note that all of the pesticides used were insecticides. It is not clear why pesticides to control plant pathogens were not used. Such a high use of insecticides suggests that farmers do not recognize the symptoms of diseases or perhaps there is a misperception that insecticides can also control plant diseases. Further studies are needed to understand farmers' knowledge, behavior and perceptions of integrated pest management.

Irrigation

The most common form of irrigation across all four crops was by using a bucket or watering can (Fig. 7).

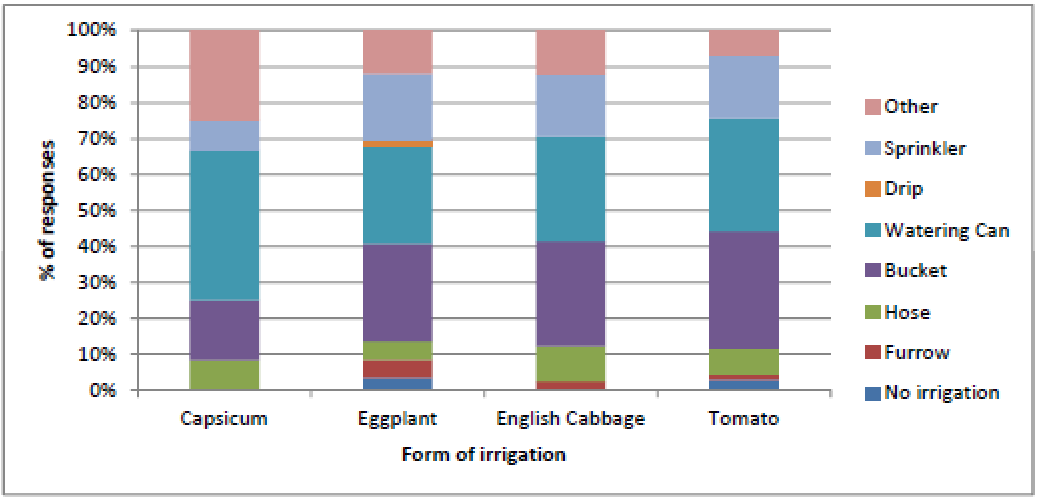

Figure 7: Forms of irrigation by crop (%. of responses per crop)[23]

[23] Please note 5 of the 12 responses for capsicum were for watering can. Consequently, the percentage of responses was high, but based on a small number of observations.

The use of sprinklers was the third most common method overall and particularly used for eggplant[24]. A significant number (11% of responses) also named alternative methods, including flood irrigation and the use of spray backpacks to irrigate crops. These forms of irrigation were likely to be supplementary to rainwater. It is not known how many of the respondents had coverings over their crops, but it is likely to be relatively few.

Constraints to production

Figure 8 shows the key constraints for production for each of the main vegetables. The greatest reported constraint for eggplant, English cabbage and tomatoes is severe pest damage. The second most common answer was 'other' (31% of responses to the question on the most important constraint). Most (60%) of the answers provided under 'other' were related to flooding and weather challenges. Clearly flooding is a key concern for vegetable producers. This correlates with the earlier finding that most of the respondents have experienced flooding in the last five years. Other constraints such as lack of capital, lack of irrigation, lack of new seed varieties etc., received a minority of the responses overall.

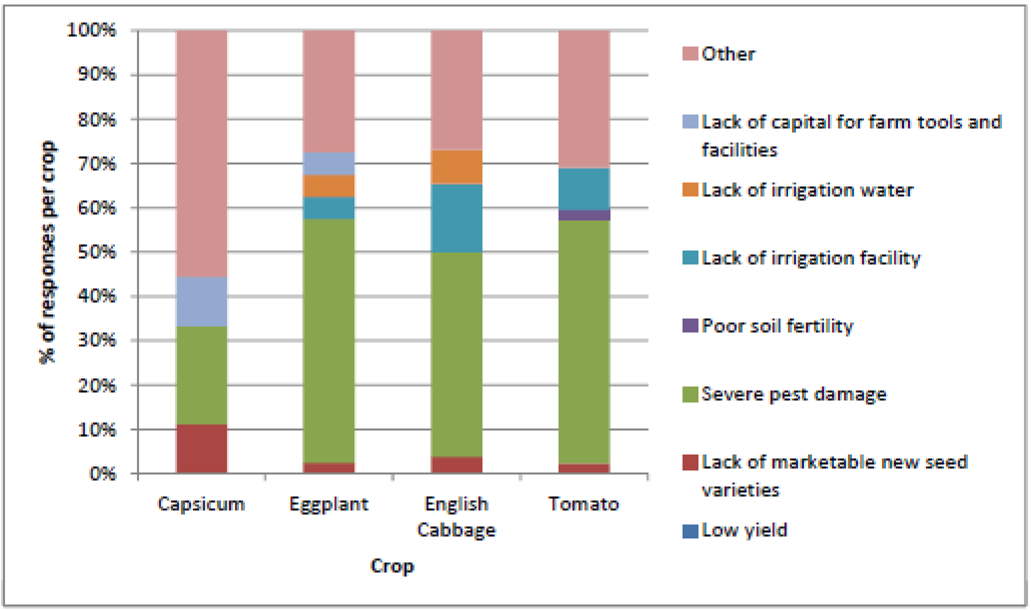

Figure 8: Main constraint to production (% of responses per crop)

A study conducted by Young and Vinning (2007) on horticultural production, which questioned 238 farmers in the Sigatoka valley and the Cane Coastal Area, asked a similar question regarding constraints. Interestingly they found that for tomato production the greatest constraint was lack of water irrigation with pests and disease coming in second. This could indicate that further clarification is required concerning major constraints tomato producers face, particularly around irrigation issues.

Postharvest handling techniques

Early morning was the most common time of day to harvest produce for all crops except tomatoes, which were typically collected in the afternoon. Collection appears to be done quickly, with no respondents reporting a time between harvest and collection longer than a day. Tomatoes showed greater variability in the time of harvesting. This is because they were picked and allowed to ripen on the farm before being taken to market. They can, therefore, be harvested later in the day and most tomato farmers responded that they harvested in the afternoon (Fig. 9).

[24] Nineteen percent of responses regarding eggplant said that sprinklers were used for irrigation. This was the highest percentage of 'sprinkler' responses for any of the crops considered (see Annex 3, E12)

A study on postharvest handling of tomatoes in Fiji (Underhill 2013) found that tomatoes were left to ripen on the farm between one and four days after harvesting and before collection. It is recommended that tomatoes are picked just as their color begins to change from green to red. Interestingly, this appears to not be the common practice of most tomato farmers. Tomatoes were often picked while they were still green, and ripened on the farm. The consequences of this were twofold:

1) 8.9% of the harvest failed to ripen in time and was wasted; and,
2) Tomatoes were placed in high temperatures to precipitate ripening; 8.8% of the harvest was then lost as the tomatoes became overripe or rotted in the high temperatures.

It is likely that the current practices are the most convenient for the farmer, but these practices do lead to a significant loss of harvest and therefore profit.

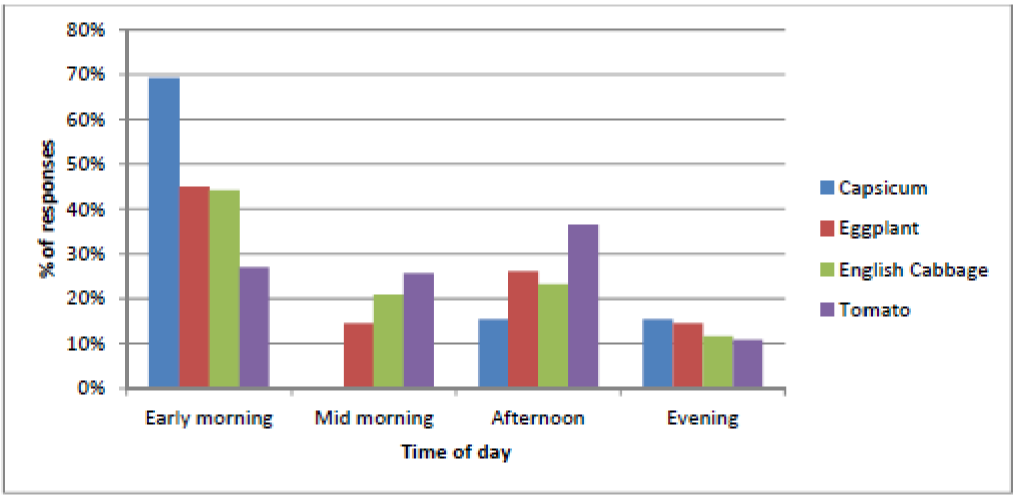

Figure 9: Time of day for harvest (% of responses per crop)

Once harvested, farmers typically filled bags with the produce, which were then kept on the ground or under the shade of a tree before being transported. This practice was used for all types of vegetables. However, there was some difference in whether produce was graded on not (Fig. 10).

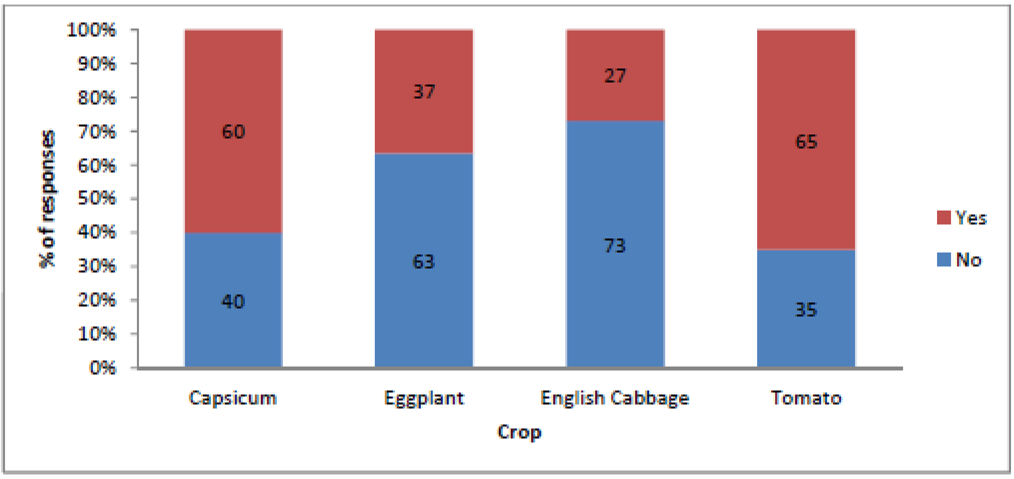

Figure 10: Grading/sorting of vegetables (% of responses per crop)

Postharvest grading was more commonly done for tomatoes and capsicum, whereas the majority of eggplant and English cabbage farmers said they did not grade or sort the crop after harvest. Sorting of tomatoes was done by a large number of criteria but the most important were the existence of blemishes, size and color.

Young and Vinning (2007) found that producers predominantly grade products according to the buyers' criteria. This suggests that buyers have more stringent criteria for capsicum and tomatoes.

Eggplant, English cabbage and capsicum were normally transported in various forms of bags, including flour bags, onion bags, crest bags, sacks and woven bags. Tomatoes were mainly transported in wooden crates, most likely to prevent bruising, which was an important grading criterion for tomatoes.

Marketing

Markets

The majority (58% of responses) of farmers sold their produce at local markets such as Suva, Sigatoka and Nadi. The questionnaire considered in this analysis did not cover transportation to market, but the study conducted by Young and Vinning (2007) revealed that transportation is a major issue for vegetable farmers. Table 6 shows the average distances travelled by producers. Approximately half (44%) of the producers interviewed had to transport their produce 10 km or more from the production place to their selling point. Nine percent had to transport it more than 50 km. Given the generally poor condition of the roads in these areas, transportation is often slow and expensive.

Table 6: Distances travelled by producers to transport produce to market

Distance to market (km)	Percentage of producers interviewed
0	10%
1-5	19%
6-10	27%
11-15	11%
16-20	9%
21-50	15%
>50	9%
Total	100%

Source: Young and Vinning (2007:84)

Only a minority (10% of responses) sold any of their produce to the export market or to resorts and hotels. Of the farmers supplying export markets and hotels, seven households were identified as selling a high percentage (more than 50%) of multiple vegetable crops to these markets. Interestingly, the average farm size of these households was just less than three acres. Also, none of the farms greater than 10 acres reported any sale for export and predominantly sold in local markets. This finding is at odds with expectations. This could indicate problems with the data but is worthy of further investigation in future work.

Typically, farmers kept around 10% of their harvest for home consumption. Farmers also tended to sell to just one key market, e.g. export market or a local market, and sold more than 50% of their produce to that one market.

Sales channels

Most farmers sold produce to markets through middlemen rather than directly themselves (Fig. 11). Perhaps surprisingly, most respondents who sold multiple products to resorts or for export, reported selling the produce directly rather than through a middleman. Again, this is contrary to what we might expect from commercial farmers.

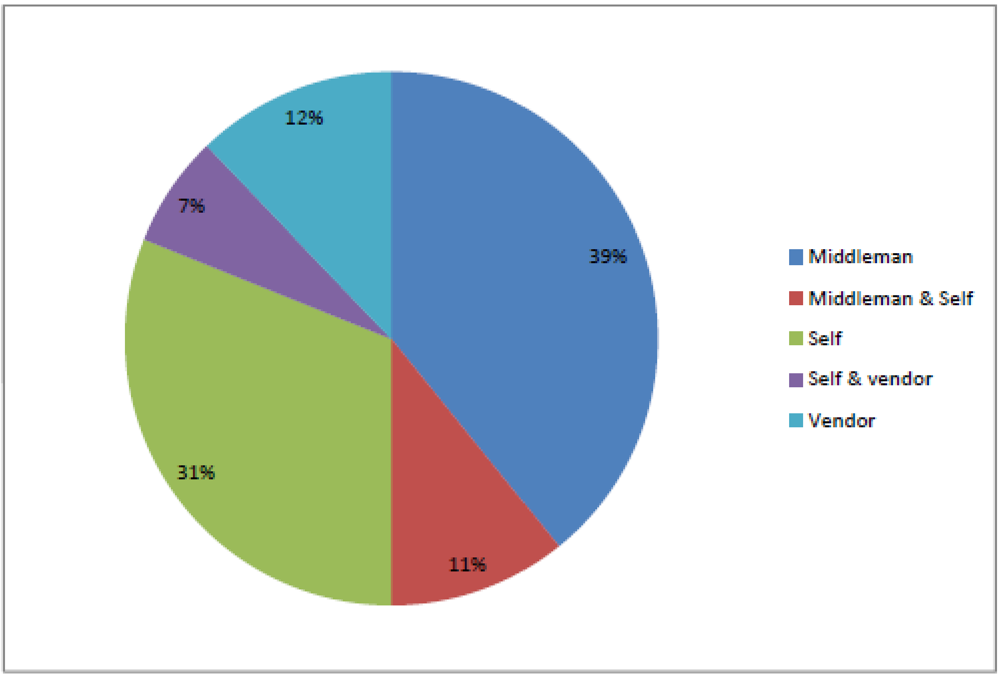

Figure 11: Sales channels, breakdown of responses (% of respondents)

Prices and seasonality

Respondents were asked to note which months had low or high prices for their three main crops. Most respondents thought there was an increase in prices around March/April. Prices then dropped significantly around August/September and the end of the dry season. This did not seem to change no matter who sold the produce (e.g. middlemen, self or direct to vendors) or which crop it was.

When asked the reason for this, the most common answer was that it was due to increases and decreases in the supply of produce. High levels of supply around the main harvesting period led to depressed prices.

This corresponds with market data collected by MAFF. Figure 12 shows prices for the main crops considered in this analysis in 2011 and 2012. The prices were collected on a monthly basis and averaged for the main markets in Fiji. Prices increased from January to around May with a large drop in prices across all vegetables around September.

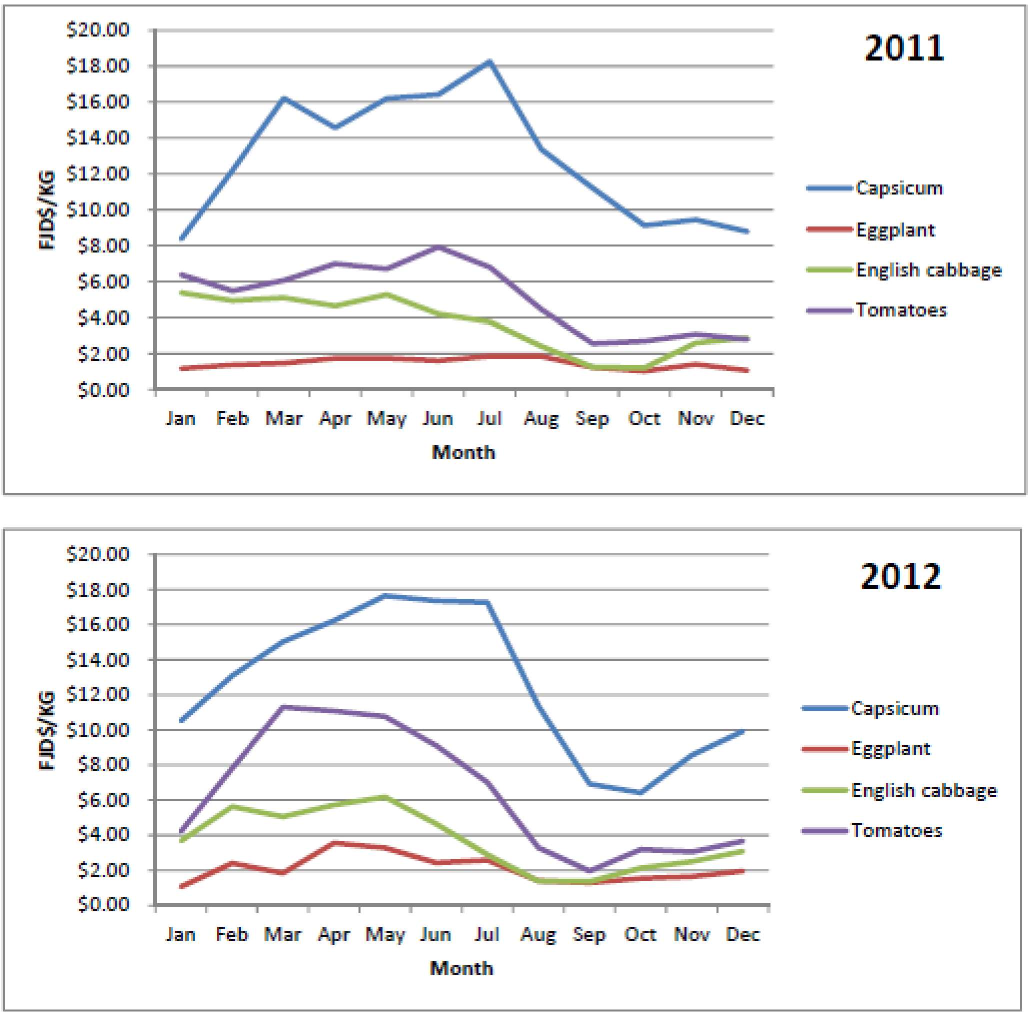

Figure 12: Prices for tomatoes, eggplant and English cabbage in main markets in Fiji (2011 and 2012)

Source: (AgTrade Unit, MAFF)

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Conclusion

Based on the results of this questionnaire, Fijian vegetable producers were predominantly male, aged 40 years old and above. They were mainly smallholder farmers that relied on family labor and worked the land by hand or with animal traction.

The most common vegetables produced were tomatoes, eggplants and English cabbage. Fertilizer use was very common but was generally limited to NPK and Urea, with very few farmers using other fertilizers such as manure. Since the fertility of the soil in the areas studied was often not optimal, greater use of manures and compost would be beneficial for vegetable production.

Pesticide use was also high with nearly all farmers using one or more pesticide. There was a large range of pesticides used despite a high level of commonality between the pests reported for the different vegetables. It appears that many farmers applied broad spectrum pesticides because either they were unable to identify the particular pest or disease attacking their crop, or could not select an appropriate pesticide. Farmers also applied pesticides frequently, most often on a weekly or fortnightly basis. Contradictions in the answers of the farmers regarding pest management suggest further research in this area would be warranted. Farmers identified pests as the greatest constraint to production for all of the main crops; it thus would be useful to understand why farmers choose the pesticides that they do and whether the high application rates are justified. Such insight would support the design of interventions to remove this constraint to the production of high value vegetables.

Flooding appears to be another constraint to production. Many of the farmers surveyed lived around the banks of the Sigatoka River and were regularly subjected to floods, particularly the catastrophic floods of 2009 and 2012. Perhaps surprisingly, only 10 farmers reported the installation of improved drainage systems despite the high level of flooding experienced. Addressing issues around flooding and drainage may be a suitable area for intervention.

Most farmers sold the majority of their produce in local markets such as Suva and Nadi. Typically they used middlemen to sell their products, although a high number of farmers also sold their produce directly. The reliance of producers on the domestic market means they were highly susceptible to highs and lows in prices driven by market supply.

Just 10% of farmers reported selling any of their produce to resorts, hotels or for export. Interestingly, these farmers were not the respondents with the largest farms but had an average farm size of just under three acres. In general respondents with larger farms did not conform to commercial production practices. For example, they did not use a greater amount of permanent or contract workers; they predominantly served local markets rather than hotels, and they tended to sell their produce directly. This unexpected result could be due to the small number of respondents with farms greater than 10 acres (9 respondents). Nevertheless, it would be interesting to investigate further the differences in vegetable production between farmers with different sized landholdings.

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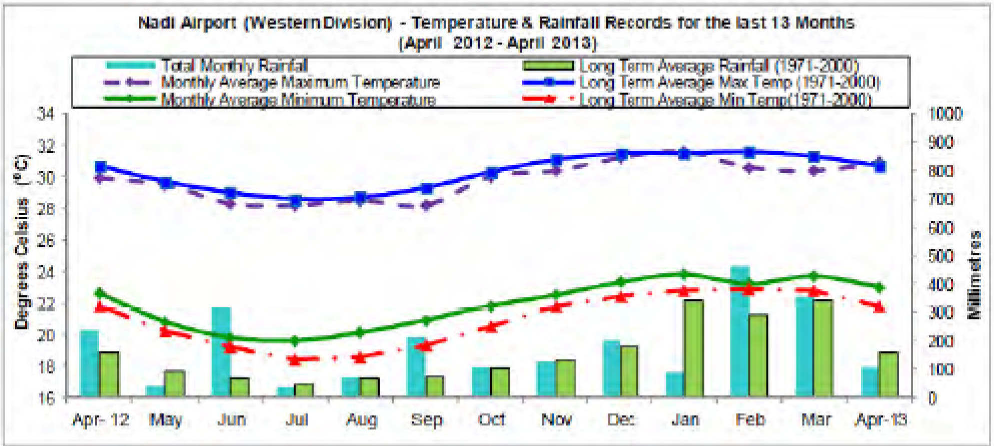
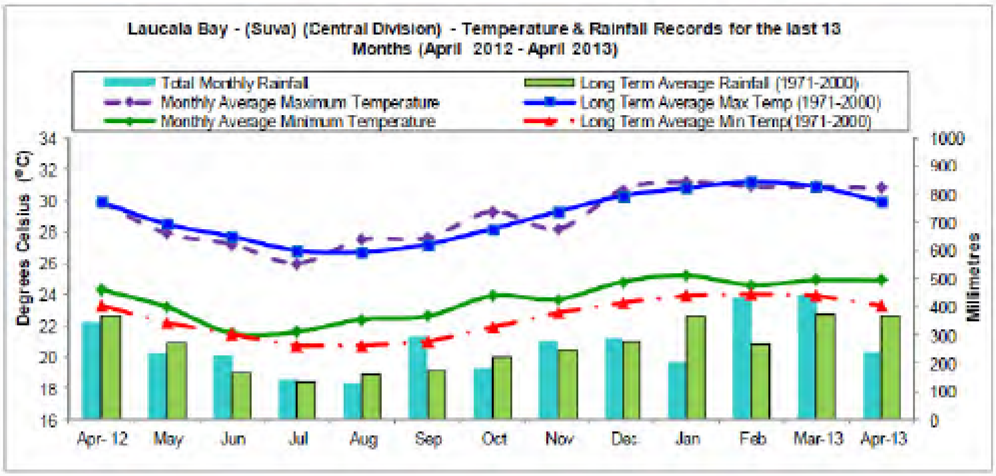
Annexes

Annex 1: Survey sites in Viti Levu

Annex 2: Monthly temperature and rainfall of survey sites





Source: Fiji Climate Summary April 2013; http://www.met.gov.fj/Summary1.pdf

Nadi data was used to represent Sigatoka and Cane Coastal Area, while Suva data was used to represent Koronivia.

Annex 3. Detailed breakdown of questionnaire

SECTION A: TRACKING INFORMATION

A3: Form filled at:

Answer	No.	% of total
Sigatoka-Lower valley	19	24%
Sigatoka-Middle valley	14	18%
Sigatoka-East bank	32	40%
Cane coastal area	10	13%
Koronivia	5	6%

Total no of respondents	80
Total no of responses	80

SECTION B: SOCIO-DEMOGRAPHIC INFORMATION

B2: Age:

Answer	No.	% of total
Between 20 & 30	8	10%
Between 31 & 40	15	19%
Between 41 & 50	29	37%
Older than 50	27	34%

Total no of respondents	79
Total no of responses	79

B3: Sex:

Answer	No.	% of total
Male	75	94%
Female	5	6%

Total no of respondents	80
Total no of responses	80

B4 Ethnicity of respondent:

Answer	No.	% of total
Indo Fijian	44	55%
I-Taukei	36	45%
Other	0	0%

Total no of respondents	80
Total no of responses	80

B4-1 Highest level of education of respondent

Answer	No.	% of total
None	2	3%
Attended primary	15	19%
Completed primary	22	28%
Attended secondary	32	40%
Completed secondary	6	8%
Other (specify)	3	4%

'Other' specified	No.	% of 'other'
Tertiary	3	100%

Total no of respondents	80
Total no of responses	80

B5 Do you have any farm in another location? (record the total number of farms)

Answer	No.	% of total
1	61	76%
2	17	21%
3	0	0%
4	1	1%
5	1	1%

Total no of respondents	80
Total no of responses	80

B6 How many people live in your house?

Answer	No.	% of total
0	2	3%
1	2	3%
2	7	9%
3	15	19%
4	19	24%
5	12	15%
6	13	16%
7	3	4%
8	4	5%
9	0	0%
10	1	1%
12	1	1%
15	1	1%

Total no of respondents	80
Total no of responses	80

B7 Of these, how many are children 10 years and younger?

Answer	No.	% of total
1	57	71%
2	13	16%
3	7	9%
4	2	3%
5	0	0%
6	1	1%

Total no of respondents	80
Total no of responses	80

B8 Are you a member of any agricultural related community group?

Answer	No.	% of total
No	28	35%
Yes	52	65%

Total no of respondents	80
Total no of responses	80

SECTION C: FARM INFORMATION

C1 What type of farming do you do?

Answer	No.	% of total
Only vegetables	22	28%
Fruits and vegetables	44	55%
Crops and livestock	14	18%

Total no of respondents	80
Total no of responses	80

C2 What type of farming system do you practice?

Answer	No.	% of total
Hand implements	5	6%
Animal traction	29	36%
Hand and animal	11	14%
Hand and tractor	1	1%
Animal and tractor	20	25%
Tractor	7	9%
All	7	9%

Total no of respondents	80
Total no of responses	80

C3 What is the total area of your farm?

Answer	No.	% of total
<1 acre	3	4%
1<5 acres	35	44%
5<10 acres	32	41%
10<15 acres	5	6%
15<20 acres	2	3%
20<25	1	1%
25<30	1	1%

Total no of respondents	80
Total no of responses	79

C4 What is the nature of the tenure

Answer	No.	% of total
Freehold	20	25%
Crown lease	0	0%
NLTB lease	16	20%
Sharecropping	6	8%
Sharecropping & freehold	2	3%
Sharecropping & NLTB	1	1%
Sharecropping & Mataqali	1	1%
Mataqali	33	41%
Other	1	1%

Total no of respondents	80
Total no of responses	80

C5 **How much of the total area of your farm are vegetables grown in?**

Answer	No.	% of total
<1 acre	5	6%
1<2 acres	12	15%
2<3 acres	13	17%
3<4 acres	15	19%
4<5 acres	13	17%
5<6 acres	11	14%
6<7 acres	5	6%
7<8 acres	1	1%
8<9 acres	0	0%
9<10	2	3%
20	1	1%

Total no of respondents	80
Total no of responses	78

C6 **What are your three main vegetable crops?**

Answer	No.	% of total
Tomato	44	18%
Eggplant	41	17%
None selected	27	11%
English cabbage	26	11%
Long bean	22	9%
Chinese cabbage	14	6%
Okra	14	6%
Cucumber	13	5%
Capsicum	10	4%
Cowpea	9	4%
French bean	4	2%
Bele	3	1%
Bean	2	1%
Corn	2	1%
Lettuce	2	1%
Pumpkin	2	1%
Watermelon	2	1%
Zucchini	2	1%
Peanut	1	0%

Total no of respondents	80
Total no of responses (80*3)	240

C6-2 **What time of year are the 3 major crops grown?**

Answer	Crop 1	Crop 2	Crop 3
January	46	51	31
February	45	47	38
March	53	57	43
April	67	70	44
May	82	82	51
June	106	95	66
July	109	107	70
August	117	111	74
September	106	96	63
October	81	70	42
November	52	56	39
December	47	52	27

C7 **Do you grow different varieties during different seasons?**

Answer	No.	% of total
No	60	77%
Yes	18	23%

Total no of respondents	80
Total no of responses	78

C8 **What is the typical cropping sequence for two of the fields where vegetables are grown?**

Answer	No.	% of total
All vegetable rotation	65	65%
Vegetables and root crops	6	6%
Vegetables and cereals	25	25%
No rotation	4	4%

Answer	No.	% of total
No fallow	64	64%
One fallow period	24	24%
Two fallow periods	12	12%

Total no of respondents	80
Total no of responses	100

SECTION D: SOIL HEALTH INFORMATION

D1 What is the typical soil series (or soil texture, type, if available)

Answer	No.	% of total
Don't know	56	70%
Sandy loam	19	24%
Loam soil	5	6%

Total no of respondents	80
Total no of responses	80

D2 What is the slope of your farm?

Answer	No.	% of total
Flat	71	85%
Mild slope (<15°)	13	15%
Steep (15°<30°)	0	0%
Other	0	0%

Total no of respondents	80
Total no of responses	84

D3 What of the following events has occurred in your farm in the past 5 years?)

Answer	No.	% of total
Flooding	84	88%
Land levelling	1	1%
Imported topsoil	0	0%
Improved drainage	10	11%

Total no of respondents	80
Total no of responses	95

D5 How do you till your land?

Answer	No.	% of total
Manual	29	14%
Animal	107	53%
Tractor	67	33%

Total no of respondents	80
Total no of responses	203

Answer	No.	% of total
Hoe	12	5%
Disc plough	81	35%
Harrow	83	35%
Scarifier	37	16%
Other	21	9%

Total no of respondents	80
Total no of responses	234

Answer	No.	% of total
0-5 cms	4	2%
6-10 cms	32	19%
11-15 cms	64	38%
16-20 cms	31	18%
21-25 cms	3	2%
26-30 cms	31	18%
More	5	3%

Total no of respondents	80
Total no of responses	170

Answer	No.	% of total
Before planting	158	51%
Mid-crop stage	71	23%
After harvest	82	26%

Total no of respondents	80
Total no of responses	311

D6 How do you manage crop residue?

Answer	No.	% of total
Remove from the field	35	40%
Incorporate into the soil	43	49%
Leave in the field	7	8%
Other	3	3%

Total no of respondents	80
Total no of responses	88

SECTION E: PRODUCTION INFORMATION

E1 How many people work on your farm?

Answer	No.	% of total
1	3	4%
2	33	42%
3	22	28%
4	14	18%
5	4	5%
6	3	4%

Total no of respondents	80
Total no of responses	79

E1-1 Who does what activities on your farm?

Answer	Men	%	Both	%	Women	%	No.
Weeding	28	35%	48	61%	3	4%	79
Planting	34	43%	45	56%	1	1%	80
Ploughing	74	94%	5	6%	0	0%	79
Pesticide application	72	92%	5	6%	1	1%	78
Fertiliser application	47	63%	26	35%	2	3%	75
Transport	68	92%	2	3%	4	5%	74
Administration	65	83%	10	13%	3	4%	78
Harvesting	23	29%	56	71%	0	0%	79
Selling of produce	51	65%	14	18%	14	18%	79
Buying of inputs	70	89%	8	10%	1	1%	79

Answer	Family	%	Family/ Casual	%	Family/ contract	%	Family /Perm	%	Casual	%
Weeding	38	48%	27	34%	0	0%	1	1%	11	14%
Planting	42	53%	25	31%	0	0%	1	1%	11	14%
Ploughing	55	70%	11	14%	1	1%	1	1%	7	9%
Pesticide application	53	69%	12	16%	1	1%	0	0%	9	12%
Fertiliser application	48	64%	16	21%	0	0%	0	0%	9	12%
Transport	67	91%	2	3%	0	0%	0	0%	4	5%
Administration	78	99%	1	1%	0	0%	0	0%	0	0%
Harvesting	45	57%	23	29%	0	0%	1	1%	8	10%
Selling of produce	74	94%	2	3%	0	0%	0	0%	2	3%
Buying of inputs	79	100%	0	0%	0	0%	0	0%	0	0%

Answer	Casual/ Contract	%	Contract	%	Permanent	%	Family /mixed	%	No.
Weeding	1	1%	2	3%	0	0%	0	0%	80
Planting	1	1%	0	0%	0	0%	0	0%	80
Ploughing	1	1%	3	4%	0	0%	0	0%	79
Pesticide application	1	1%	0	0%	1	1%	0	0%	77
Fertiliser application	1	1%	0	0%	1	1%	0	0%	75
Transport	0	0%	1	1%	0	0%	0	0%	74
Administration	0	0%	0	0%	0	0%	0	0%	79
Harvesting	0	0%	0	0%	0	0%	2	3%	79
Selling of produce	0	0%	1	1%	0	0%	0	0%	79
Buying of inputs	0	0%	0	0%	0	0%	0	0%	79

E2 What equipment do you use on your farm?

Answer	Owned	%	Hired	%	Borrowed	%	Do not	%	No.
Hand tractor	1	1%	0	0%	0	0%	79	99%	80
Wheel tractor	26	33%	28	35%	0	0%	26	33%	80
Plough	64	80%	7	9%	4	5%	5	6%	80
Spraying equipment	68	85%	1	1%	7	9%	4	5%	80
Irrigation equipment	29	36%	1	1%	2	3%	48	60%	80
Hand water pump	7	9%	0	0%	0	0%	73	91%	80
Motorized wtater pump	15	19%	0	0%	0	0%	64	81%	79
Plastic crates	26	33%	1	1%	0	0%	52	66%	79
Packing/storage shed	23	29%	0	0%	0	0%	56	71%	79
Transport	19	24%	17	22%	1	1%	42	53%	79

E3 What is your source of water?

Answer	No	% of total
Nearby river	64	81%
Borehold	2	3%
Well	4	5%
Other	9	11%

Total no of respondents	80
Total no of responses	79

E3-1 How far is your source of water supply from the field (m)?

Answer	No.	% of total
<=10	13	16%
10<50	22	28%
50<100	11	14%
100<200	11	14%
200<500	15	19%
500<1000	7	9%
>1000	1	1%

Total no of respondents	80
Total no of responses	80

E5 Where do you source your seed from?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	%
	No.	%	No.	%	No.	%	No.	%		
Research station	1	10%	13	29%	3	11%	5	10%	22	17%
TTM	0	0%	1	2%	0	0%	0	0%	1	1%
Local stores	9	90%	23	51%	24	89%	43	90%	99	76%
Own saved seed	0	0%	7	16%	0	0%	0	0%	7	5%
Other farmers	0	0%	1	2%	0	0%	0	0%	1	1%
Other (specify)	0	0%	0	0%	0	0%	0	0%	0	0%
Total	10	100%	45	100%	27	100%	48	100%	130	100%

E9 Do you use fertiliser on this crop? (capsicum, eggplant, English cabbage & tomatoes)

Answer	No.	% of total
No	3	2%
Yes	118	98%

Total no of respondents	80
Total no of responses	121

E9-1 Fertiliser type

Answer	Tomato		Eggplant		English Cab		Total	
	No.	%	No.	%	No.	%	No.	%
Pig manure	0	0%	0	0%	0	0%	0	0%
Chicken manure	4	5%	5	6%	3	6%	12	6%
Compost	1	1%	1	1%	1	2%	3	1%
Urea	39	44%	33	43%	25	49%	97	45%
NPK	42	48%	35	45%	21	41%	98	45%
Liquid fertiliser	2	2%	3	4%	1	2%	6	3%
Total no of respondents	80							
Total no of responses	88		77		51		216	

E10 Do you use commercial pesticides on this crop (capsicum, eggplant, English cabbage & tomatoes)

Answer	No.	% of total
No	9	8%
Yes	111	93%

Total no of respondents	80
Total no of responses	120

E10-3 Do you use methods other than synthetic pesticides to control pests?

Answer	No.	% of total
No	116	96%
Yes	5	4%

Total no of respondents	80
Total no of responses	121

E11 How do you make pest management decisions?

Answer	No.	% of total
Own experience	51	17%
Damage seen on crop	87	29%
Crop monitoring	68	23%
Extension staff recommendations	18	6%
Learned from other farmers	35	12%
Pesticide retailers recommendations	8	3%
Programme according to stage of crop	21	7%
Programme according to time of year	10	3%
Other	1	0%

Total no of respondents	80
Total no of responses	299

E12 How do you water this crop?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
No irrigation	0	0%	2	3%	0	0%	2	3%	4	2%
Furrow	0	0%	3	5%	1	2%	1	1%	5	3%
Hose	1	8%	3	5%	4	10%	5	7%	13	7%
Bucket	2	17%	16	27%	12	29%	23	33%	53	29%
Watering Can	5	42%	16	27%	12	29%	22	31%	55	30%
Drip	0	0%	1	2%	0	0%	0	0%	1	1%
Sprinkler	1	8%	11	19%	7	17%	12	17%	31	17%
Other	3	25%	7	12%	5	12%	5	7%	20	11%

Total no of respondents	80				
Total no of responses	12	59	41	70	182

E14 What time of day do you harvest your produce?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Early morning	9	69%	31	45%	19	44%	20	27%	79	40%
Mid-morning	0	0%	10	14%	9	21%	19	26%	38	19%
Afternoon	2	15%	18	26%	10	23%	27	36%	57	29%
Evening	2	15%	10	14%	5	12%	8	11%	25	13%

Total no of respondents	80				
Total no of responses	13	69	43	74	199

E14-2 During harvesting, where do you keep your produce?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
On the ground	0	0%	14	26%	15	33%	14	22%	43	25%
Under a tree	5	50%	19	35%	10	22%	15	23%	49	28%
In the open	0	0%	6	11%	9	20%	6	9%	21	12%
Under a shelter	2	20%	9	17%	7	16%	12	18%	30	17%
In a shed	1	10%	5	9%	2	4%	11	17%	19	11%
Other	2	20%	1	2%	2	4%	7	11%	12	7%

Total no of respondents	80				
Total no of responses	10	54	45	65	174

E14-3 Do you grade or sort produce after harvest?

Answer	Capsicum No.	Capsicum %	Eggplant No.	Eggplant %	English Cab No.	English Cab %	Tomato No.	Tomato %	Total No.	Total %
No	4	40%	26	63%	19	73%	15	35%	64	53%
Yes	6	60%	15	37%	7	27%	28	65%	56	47%

Total no of respondents	80				
Total no of responses	10	41	26	43	120

E14-4 What criteria do you use to grade?

Answer	Capsicum No.	Capsicum %	Eggplant No.	Eggplant %	English Cab No.	English Cab %	Tomato No.	Tomato %	Total No.	Total %
Size	6	40%	12	33%	7	47%	21	27%	46	32%
Colour	4	27%	2	6%	2	13%	16	20%	24	17%
Maturity	1	7%	8	22%	3	20%	13	16%	25	17%
Blemishes	4	27%	13	36%	3	20%	26	33%	46	32%
Weight	0	0%	0	0%	0	0%	0	0%	0	0%
Other	0	0%	1	3%	0	0%	3	4%	4	3%

Total no of respondents	80				
Total no of responses	15	36	15	79	145

E14-5 Do you wash produce after harvest?

Answer	Capsicum No.	Capsicum %	Eggplant No.	Eggplant %	English Cab No.	English Cab %	Tomato No.	Tomato %	Total No.	Total %
No	2	20%	34	83%	23	88%	32	74%	91	76%
Yes	8	80%	6	15%	3	12%	11	26%	28	23%

Total no of respondents	80				
Total no of responses	10	40	26	43	119

E14-6 What time of day is your produce collected or delivered?

Answer	Capsicum No.	Capsicum %	Eggplant No.	Eggplant %	English Cab No.	English Cab %	Tomato No.	Tomato %	Total No.	Total %
Morning	2	20%	5	12%	4	15%	6	15%	17	15%
Afternoon	3	30%	20	49%	6	23%	13	33%	42	36%
Evening	0	0%	3	7%	7	27%	5	13%	15	13%
As soon as its ready	1	10%	7	17%	5	19%	5	13%	18	15%
Next day	4	40%	6	15%	4	15%	3	8%	17	15%
Longer than a day	0	0%	0	0%	0	0%	5	13%	5	4%
Other	0	0%	0	0%	0	0%	3	8%	3	3%

Total no of respondents	80				
Total no of responses	10	41	26	40	117

E14-7 What kind of packaging do you use?

Answer	Capsicum No.	Capsicum %	Eggplant No.	Eggplant %	English Cab No.	English Cab %	Tomato No.	Tomato %	Total No.	Total %
Plastic crate	3	30%	3	7%	0	0%	4	10%	10	9%
Wooden crate	0	0%	0	0%	0	0%	37	93%	37	32%
Woven bag	2	20%	22	54%	11	42%	2	5%	37	32%
Plastic bag	0	0%	0	0%	0	0%	0	0%	0	0%
Other	5	50%	19	46%	15	58%	2	5%	41	35%

Total no of respondents	80				
Total no of responses	10	44	26	45	125

'Other' specified	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Flour bags	1	20%	13	68%	9	60%	0	0%	23	56%
Onion bags	3	60%	0	0%	1	7%	1	50%	5	12%
Cartons	1	20%	0	0%	0	0%	1	50%	2	5%
Crest bags	0	0%	4	21%	4	27%	0	0%	8	20%
Sacks	0	0%	2	11%	0	0%	0	0%	2	5%
Packed in the trunk	0	0%	0	0%	1	7%	0	0%	1	2%

Total no of 'other' responses	5	19	15	2	41

E15 What are the main constraints in your vegetable production?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Low yield	1	4%	4	4%	0	0%	3	3%	8	3%
Lack of new marketable seed varieties	6	24%	11	12%	8	14%	15	15%	40	15%
Severe pest damage	4	16%	31	34%	19	33%	30	30%	84	31%
Poor soil fertility	1	4%	0	0%	0	0%	2	2%	3	1%
Lack of irrigation facility	2	8%	7	8%	6	11%	12	12%	27	10%
Lack of irrigation water	1	4%	6	7%	6	11%	5	5%	18	7%
Lack of capital to purchase farm tools	3	12%	11	12%	5	9%	10	10%	29	11%
Other	7	28%	20	22%	13	23%	23	23%	63	23%

Total no of respondents	80				
Total no of responses	25	90	57	100	272

'Other' specified	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Flooding/climate	3	43%	11	55%	8	62%	11	48%	33	52%
High cost of inputs/agrochemicals	2	29%	5	25%	2	15%	6	26%	15	24%
Lack of market/market price	1	14%	2	10%	1	8%	2	9%	6	10%
Marketing	0	0%	0	0%	1	8%	1	4%	2	3%
Distance of farm	1	14%	0	0%	0	0%	0	0%	1	2%
Price fluctuation	0	0%	1	5%	0	0%	0	0%	1	2%
Poor drainage	0	0%	1	5%	1	8%	0	0%	2	3%
Wilting	0	0%	0	0%	0	0%	1	4%	1	2%
Impure varieties	0	0%	0	0%	0	0%	1	4%	1	2%
Packaging materials	0	0%	0	0%	0	0%	1	4%	1	2%

Total no of 'other' responses	7	20	13	23	63

E15-1 Which one is the most important constraint?

Answer	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Low yield	0	0%	0	0%	0	0%	0	0%	0	0%
Lack of marketable new seed varieties	1	11%	1	3%	1	4%	1	2%	4	3%
Severe pest damage	2	22%	22	55%	12	46%	23	55%	59	50%
Poor soil fertility	0	0%	0	0%	0	0%	1	2%	1	1%
Lack of irrigation facility	0	0%	2	5%	4	15%	4	10%	10	9%
Lack of irrigation water	0	0%	2	5%	2	8%	0	0%	4	3%
Lack of capital for farm tools	1	11%	2	5%	0	0%	0	0%	3	3%
Other	5	56%	11	28%	7	27%	13	31%	36	31%

Total no of respondents					
Total no of respondses	9	40	26	42	117

'Other' specified	Capsicum		Eggplant		English Cab		Tomato		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Flooding/climate	3	43%	7	70%	4	57%	7	58%	21	58%
High cost of inputs/agrochemicals	2	29%	0	0%	0	0%	1	8%	3	8%
Lack of market/market price	1	14%	2	20%	1	14%	2	17%	6	17%
Marketing	0	0%	0	0%	1	14%	1	8%	2	6%
Distance of farm	1	14%	0	0%	0	0%	0	0%	1	3%
Price fluctuation	0	0%	0	0%	0	0%	0	0%	0	0%
Poor drainage	0	0%	1	10%	1	14%	0	0%	2	6%
Wilting	0	0%	0	0%	0	0%	0	0%	0	0%
Impure varieties	0	0%	0	0%	0	0%	0	0%	0	0%
Packaging materials	0	0%	0	0%	0	0%	1	8%	1	3%

Total no of 'other' responses	7	10	7	12	36

SECTION F: MARKETING INFORMATION

F1: What are the main markets for the three major crops (record as % of total crop marketed)

Answer	Export		Resort		Suva		Sigatoka		Nadi	
	No.	%	No.	%	No.	%	No.	%	No.	%
<=10%	1	6%	1	5%	0	0%	7	8%	4	21%
<=20%	2	11%	0	0%	3	3%	6	7%	6	32%
<=30%	6	33%	3	16%	5	5%	1	1%	2	11%
<=40%	0	0%	0	0%	0	0%	6	7%	0	0%
<=50%	7	39%	1	5%	11	11%	13	15%	0	0%
<=60%	0	0%	1	5%	9	9%	1	1%	0	0%
<=70%	0	0%	0	0%	6	6%	0	0%	0	0%
<=80%	0	0%	7	37%	12	12%	3	3%	0	0%
<=90%	0	0%	3	16%	15	14%	9	10%	3	16%
<=100%	2	11%	3	16%	43	41%	43	48%	4	21%

Total no of respondents	72									
Total no of responses	18	1	19	1	104	1	89	1	19	1

Answer	Home		Other		Total	
	No.	%	No.	%	No.	%
<=10%	79	96%	4	12%	96	26%
<=20%	0	0%	7	21%	24	7%
<=30%	0	0%	0	0%	17	5%
<=40%	0	0%	1	3%	7	2%
<=50%	3	4%	1	3%	36	10%
<=60%	0	0%	0	0%	11	3%
<=70%	0	0%	0	0%	6	2%
<=80%	0	0%	3	9%	25	7%
<=90%	0	0%	1	3%	31	9%
<=100%	0	0%	16	48%	111	30%

Total no of respondents				
Total no of responses	82	1	33	364

F2: Who sells your produce to the market?

Answer	No.	%
Middleman	51	37%
Self	87	63%
Sold to vendor	1	1%

Total no of respondents	74
Total no of responses	139

F4: Do prices increase/decrease during the year for each crop?

Answer	Eggplant		English Cab		Tomato		All	
	High	Low	High	Low	High	Low	High	Low
January	10	16	16	1	30	1	95	36
February	13	16	21	1	33	2	114	38
March	18	10	21	1	34	1	112	26
April	18	5	14	5	18	5	88	28
May	20	10	8	10	13	12	72	62
June	24	16	3	20	6	30	65	115
July	21	19	0	25	3	38	52	134
August	12	21	2	23	1	40	39	131
September	12	19	6	19	0	36	40	114
October	12	15	6	13	10	19	53	77
November	11	18	6	7	19	8	71	55
December	7	18	10	3	19	5	65	48

G CAPITAL AND SOCIOECONOMIC STATUS

G1-1 What is your total annual income?

Answer	No.	%
$0-1,000	7	9%
$1,001-5,000	25	31%
$5,001-15,000	39	49%
$15,001-25,000	2	3%
$25,000>	0	0%
Don't know	2	3%
Prefer not to say	5	6%

Total no of respondents	80
Total no of responses	80

G1-1 Is vegetable production your main source of income?

Answer	No.	% of total
No	23	29%
Yes	57	71%

Total no of respondents	80
Total no of responses	80

G3 What other activities do you do to earn an income?

Answer	No.	% of total
Livestock	17	21%
Poultry	6	8%
Fruit	35	44%
Sugarcane	0	0%
Employment on another farm	1	1%
Middleman or market vendor	0	0%
Other	29	36%

Total no of respondents	80
Total no of responses	80

'Other' specified	No.	% of total
Root crops	12	41%
Other crops	5	17%
Fish	1	3%
Tobacco/small business	4	14%
None	7	24%
Total no of 'other'responses	29	

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11.8 Appendix 8: Fiji Soil Health Survey Report

Soil Health Status in Vegetable Production Areas of Fiji
May 2013

AVRDC The World Vegetable Center

Australian Government Australian Centre for International Agricultural Research

Ministry of Primary Industries Department of Agriculture

1

INTRODUCTION

Improper soil management practices, such as over-intensive cultivation, limited crop rotation, lack of organic matter replenishment and over tillage, could lead to poor soil quality and reduce crop productivity. Consequently, soil degradation becomes a common problem in many fields of the world.
Soil health management concept integrates soil physical, chemical and biological properties for sustainable soil management. The selection of its indicator emphasizes the easiness of measurement which could be accessible and affordable by smallholder farmers. Meanwhile, the indicators are meaningful and responsible to common management practices that farmers use for crop cultivation. Therefore, soil health concept has recently received the attention of scientists and extentionists worldwide as a mean to evaluate soil degradation status following different land use and management practices and to provide recommendations for counter actions. Soil is the most valuable asset for smallholders. A simple protocol with proper education would motivate smallholders to take initiative to monitor and improve soil health condition in their fields.

In the past, soil management tends to only focus on chemical properties (fertility, nutrient level, etc.), not paying sufficient attention on physical and biological properties. Inexpensive soil testing procedures to assess the chemical (fertility) properties were extensively studied, but methods for rapid assessment of soil physical and biological status were generally not available. Several research groups (2) have developed a systematic approach to characterize soil health which transcends the conventional soil nutrient analysis. The approach included 1) identifying the soil processes and functions needed for soil health assessment; 2) testing potential soil quality indicators; 3) developing appropriate protocols for soil health; 4) developing criteria for interpreting soil health indicators in an agronomically meaningful way; and 5) recommending improved soil management practices based on soil health assessment that will ensure economic viability, environmental safety and social acceptability (4 & 5).

Soil Health – the key concept

Soil health is the integration of soil physical, chemical and biological processes and functions with emphasis of the holistic approach to soil management. A healthy soil will be balanced for all three components. Doran and Parkin (1) defined soil quality as "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health." While, a healthy soil is one that is productive and easy to manage under the intended land use and with the properties that promote the health of plants; animals and humans while also maintain environmental quality (3). Soil health is a concept that deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality. In general, soil health and soil quality are considered synonymous and can be used interchangeably (2).

The characteristics of good soil health (2) are:

- Good soil tilth
- Sufficient depth
- Sufficient but not excess supply of nutrients
- Low population of plant pathogens and insect pests
- Good soil drainage
- Large population of beneficial organisms and biological diversity
- Low weed pressure
- Free of chemicals and toxins that may harm the crop
- produces healthy, high quality crops
- Resistant to degradation
- Resilience when unfavorable conditions occur

Soil health is a measure of a soil's ability to respond to management practices for achieving the above healthy characteristics. Since soil health integrates the physical, chemical, and biological components of soil and their interactions, therefore, all of the three properties in the test kit should be measured. However, not all parameters have equal relevance to all soils and situations. A minimum data set of soil indicators, from each of the physical, chemical and biological components are selected based on their ability to indicate the soil responses for a specific land use, climate, and soil type. The kit should be used as a monitoring tool to give the general trend or direction of soil health. The results would be the bases to determine whether current management systems result in maintaining, enhancing, or degrading the soil (3).

Soil health survey in vegetable production areas in Fiji

This survey is a part of ACIAR PC2010/090 project "Strengthening integrated crop management research in the Pacific Islands in support of sustainable intensification of high-value crop production ". The objective is to understand the current soil health status in project sites. Information on soil management practices was collected by interviewing farmers during 5th Sept. to 3rd Oct. 2012 as part of a household survey. Measurements of soil health indicators were conducted from the project sites as well as Sigatoka Research Station during Sept. 2012 to Jan. 2013. Based on the survey results, important soil constraints were identified. Soil management practices for improving or sustaining soil health based on measured constraints were recommended.

Materials and methods

Survey locations

The survey was conducted in target communities in Sigatoka valley, Cane Costal Area and Koronivia where the project will work closely to enhance their capacity on vegetable production and marketing. A total of fifteen survey locations were identified, including thirteen farms in target communities and two plots in Sigatoka Research Station. Detailed information of selected locations was listed in Table 1. Three samples and measurements were collected and conducted in each survey farm. Location of the survey farms are showed on the satellite images (Figs 1 & 2). In order to better interpret the data, all survey farms were grouped based on their locations and communities as in Table 2.

Table 1. Soil sampling index (ID), name of respondent, village names, and location of farms selected for the survey

Soil ID No.	Respondent name	Village	Location
S1	Dhirend Prasad	Barara Settlement	Sigatoka (West bank)
S2	Rajen Sharma	Barara Settlement	Sigatoka (West bank)
S3	Inoke Momonakaya	Namatakula	Cane Coastal Area
S4	Vukiwale Kurisese	Qererqere Settlement	Sigatoka (West bank)
S5	Semisi Gadolo	Qererqere Settlement	Sigatoka (West bank)
S6	Ramesh Kumar	Lokia Settlement	Sigatoka (East Bank)
S7	Jeewan Singh	Lokia Settlement	Sigatoka (East Bank)
S8	Malakai Naceva	Qererqere Settlement	Sigatoka (West bank)
S9	Dharmen Kumar	Barara Settlement	Sigatoka (West bank)
S10	Arun Lal	Koronivia Settlement	Koronivia
S11	Mosese	Biausevu	Cane Coastal Area
S12	Maresilo Nasorowale	Komave	Cane Coastal Area
S13	Joeli Aminisitai Kuribua	Nawamagi	Sigatoka (East Bank)
S14	SRS Field 1	Nacocolevu	Sigatoka (West bank)
S15	SRS Field 2	Nacocolevu	Sigatoka (West bank)

Fig 1. Soil health survey sites in Viti Levu island, Fiji.

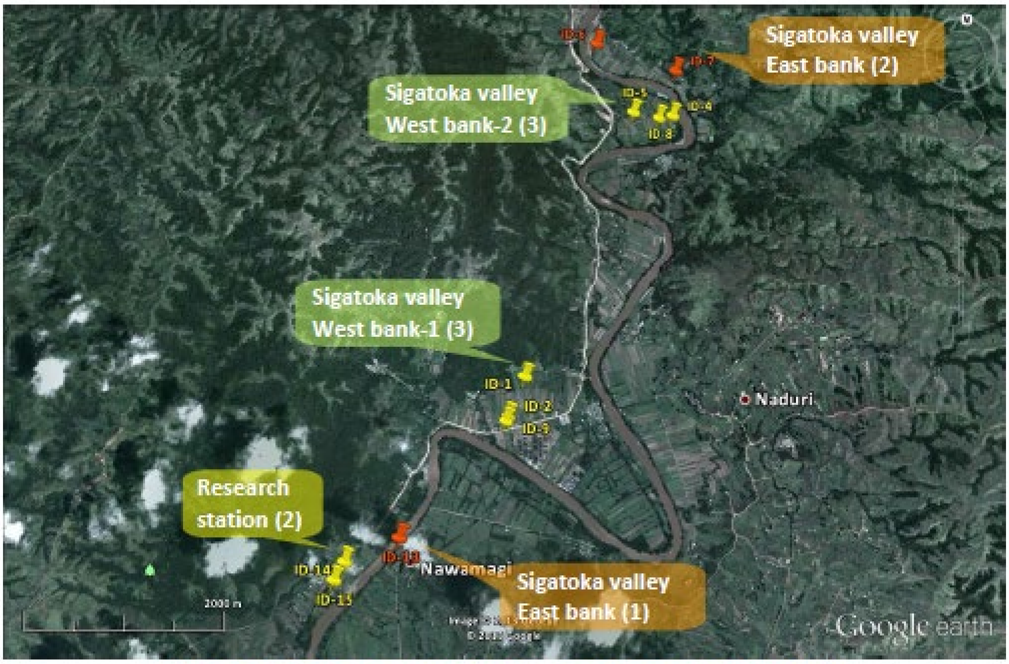

Fig 2. Soil health survey sites in Sigatoka valley (closer look)

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Table 2. Grouping of soil health survey sites according to their locations

Soil ID No.	Village	Grouping by community/location	Longitude	Latitude
S14	Nacocolevu	1. SRS1 (Research station)*	18°6'1.42" S	177°32'18.73" E
S15	Nacocolevu	1. SRS2 (Research station)	18°6'7.98" S	177°32'16.38" E
S1	Barara Settlement	2. Sigatoka-West bank1	18°4'47.14" S	177°33'11.48" E
S2	Barara Settlement	2. Sigatoka-West bank1	18°5'2.4" S	177°33'7.79" E
S9	Barara Settlement	2. Sigatoka-West bank1	18°5'4.20" S	177°33'7.31" E
S4	Qererqere Settlement	3. Sigatoka-West bank2	18°2'52.65" S	177°33'53.87" E
S5	Qererqere Settlement	3. Sigatoka-West bank2	18°2'53.87" S	177°33'37.59" E
S8	Qererqere Settlement	3. Sigatoka-West bank2	18°2'54.52" S	177°33'48.36" E
S6	Lokia Settlement	4. Sigatoka-East bank	18°2'25.35" S	177°33'17.78" E
S7	Lokia Settlement	4. Sigatoka-East bank	18°2'32.41" S	177°33'52.61" E
S13	Nawamagi	4. Sigatoka-East bank	18°5.50.48" S	177°32.36.45" E
S3	Namatakula	5. Cane coastal area	18°13'44.9" S	177°47'7.99" E
S11	Biausevu	5. Cane coastal area	18°11'34.76" S	177°43'58.76" E
S12	Komave	5. Cane coastal area	18°13'6.32" S	177°45'30.93" E
S10	Koronivia Settlement	6. Koronivia **	18° 3'25.31" S	178°32'19.69" E

* location for future soil management trial; ** location for future green manure trial

Soil Health Indicators

When selecting soil health indicators, the following criteria were considered (2 & 4) :
- Measurable at a reasonable cost
- Sensitive to changes in management practices (e.g., cover crops, tillage)
- Quantifiable effects on crop health, yield, and/or environmental impacts
- A useful integrator among several soil quality factors (e.g., aggregate stability)
- Correlated with more costly measures

Three references were used when selecting the indicators, i.e. 1) Soil Quality Test Kit Guide (10); 2) Cornell Soil Health Assessment Training Manual. Edition 2.0. (2) and 3) Soil Health Assessment Users Guide (3). Consultation was made with researchers regarding soil analytical capacity at Koronivia Research Station. Finally, the following indicators were selected.

1. Site Characterization: This information included geographic location, soil information, mean annual temperature and rainfall; present and past management practices, such as cropping system, fertilizers/pesticides, tillage/residue cover and irrigation, etc. The related questions have been incorporated into "Farm household survey questionnaires" and information was extracted.

2. Soil Infiltration Test: It measures the rate that water enters into soil and is an indicator of soil structure and compaction. Infiltration rate is dependent on the soil type; soil texture, soil structure, soil compaction, or amount of aggregation, tillage and the soil water content. The materials and stepwise procedures stated in "Soil Quality Test Kit Guide" (10) were followed.

3. Bulk Density Test: Bulk density is the ratio of oven-dried soil (mass) to its bulk volume, which includes the volume of particles and the pore space between the particles. It is a dynamic property that could be affected by soil structure, soil compaction, cultivation, and agricultural machinery, etc. It can serve as an indicator of compaction and relative restrictions to root growth. The test was conducted following the procedures stated in "Soil Quality Test Kit Guide" (10).

4. Soil Physical Observations (including topsoil depth, root growth, penetration test, soil structure and soil texture by feel).

Plant root growth in the soil can reflect crop growth above-ground. Healthy roots should be well branched with lots of fine root hairs. Restriction of lateral root growth could indicate the presence of a hardpan, or compacted layer. Penetration resistance is an easy measurement by using a penetration rod (represents root) to push into the soil. Soil texture is a measure of the relative proportions of sand, silt, and clay sized mineral particles in the soil. It is an important property which influences fertility, water intake rates, water and nutrient storage, aeration and ease of tillage. The test was conducted following the procedures described in "Soil Quality Test Kit Guide" (10). However, the "soil texture by feel method" was conducted following the procedures in "Soil Health Assessment Users Guide" (3).

5. Soil Stability Test: Soil slake test was conducted to indicate the stability of soil when exposed to rapid wetting such as heavy rain. Slaking occurs because the aggregates are not strong enough to withstand the stresses of rapid water uptake. Soil stability serves as a qualitative indicator of soil potential for crusting, erosion and root growth inhibition. The test was conducted following the procedures stated in "Soil Health Assessment Users Guide" (3).

6. Earthworm Test: Earthworm populations may vary with site characteristics, season, and species. Presence of more earthworms is an indicator of higher soil microbial activity and soil chemical fertility and good soil physical properties. However, it is common that the earthworm population density may vary greatly within the same field and could change over time. The test was conducted following the procedures for earthworm count stated in "Soil Quality Test Kit Guide" (10).

7. Soil respiration Test: The commercial kit, Solvita Soil Life Kit, was selected to measure soil respiration rate. Draeger tube method was recommended in the "Soil Quality Test Kit Guide" (10). However, it requires the Draeger tube (carbon dioxide adsorption tube), needle, and syringe. It is more difficult to be accessed and be determined by extentionists and smallholder farmers. The Solvita kit measures the CO_2 concentration generated by microbes and as an indicator of soil microbial activity. It is simple and easy to use, but quite costly (USD 20$ and 7.8$ per measurement for sample No. smaller or greater than 100, respectively). The test was conducted following the manual provided by the manufacturer (12).

8. Organic Carbon Test: Organic matter is any material that is derived from living organisms, including plants, residues and soil fauna. Organic matter in its various forms greatly impacts the physical, chemical and biological properties of the soil. It contributes to soil aggregation, water and nutrient holding capacity, and nutrients to the plant and soil microbial communities, etc. The test was conducted in soil laboratory at Koronivia Research Station using the method adapted from Walkley and Black (11).

9. Labile (Active) Carbon Test: Labile C (LC) is the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community. Labile carbon is a "leading indicator" of soil health response to changes in crop and soil management, usually responding much sooner than total organic matter content. The analyses were conducted in soil laboratory at Koronivia Research Station with the method adapted from Moody and Cong (6).

10. Soil pH Test: Soil pH is the most important soil chemical indicator. It indicated the suitability of soil for crop growth and nutrient availability. Soil acidification can also be an indication of excessive N fertilizer applications and N leaching loss. Both tools for measuring pH in field or laboratory are available. The analyses were conducted in soil laboratory at Koronivia Research Station with the method of a soil to water ratio 1:5 (8).

11. Soil EC Test: EC can be an indicator of soil soluble nutrients. A extremely low value of EC result may indicate poor soil fertility with low level of readily available nutrients (cations and anions) presented in soil solution. On the other hand, soil EC is a most critical soil chemical indicator to indicate if a soil has salinity constraint. Excess salts in soil can be a detriment to plant health. Salts can also hamper water movement into the soil and increase the occurrence of surface compaction.
The analyses were conducted in soil laboratory at Koronivia Research Station with a 1:5 soil/water extract same as those for pH measurements (7)..

12. Soil Nitrate test: Soil nitrate test measures the concentration of plant-available nitrogen, i.e. nitrate. A high level of nitrate in soil indicates N accumulation in soil as a result of over-fertiization. On the other hand, nitrate can be readily lost from the soil by leaching and volatilization. Hence it is detrimental to soil health and environmental quality. The test was conducted following the method described in "Soil Quality Test Kit Guide" (10). Instead of nitrate strips from HACH products, the nitrate test strips of Merck brand (Germany, Merckoquant, Cat. No. 1.10020.0001) were used to measure the nitrate concentration in soil extract.

The above 2nd to 6th indicators were measured in the field by MPI officers and project staffs. Part of bulk density and stability tests were also determined in the laboratory. The 7th to 12th indicators were conducted by collecting soil samples on farms and measuring at soil laboratory at Koronivia Research Station, Nausori.

Soil health survey interpretation and score functions

A challenge with soil health assessment was the interpretation of the collected data. The Cornell Soil Health Team (5) developed scoring curves to help interpret the measured values, and provided ratings on a scale of 1 to 10. Their scoring curves generally fall into three categories:

- More is better (e.g., microbial activity, soil stability, % OM, labile C)
- Less is better (e.g., pathogenic nematodes, bulk density, compaction)
- Optimum (e.g., pH, soil N, P, decomposition rate)

The scoring curves were developed based on information available from literature, expert opinion and their soil health survey database conducted in New York State. For many of the indicators, interpretations were adjusted according to the major soil textural classes of sand, silt and clay. Interpretations should be also modified based on soil type, crop, and other factors. Due to lack of soil property database in Fiji, we adopted scoring functions and criteria from the three references. A system with three scores was developed for its easiness to be interpreted and adopted by local partners and smallholder farmers. Conversion tables of each indicator are listed in Appendix 1. The meanings of the scores are:

- 0 - Poor (e.g. high bulk density, low pH, low OM)
- 1 - Moderate (e.g. moderate texture, marginal pH)
- 2 - Good (e.g. high microbial activity, high OM, good infiltration)

Results and Discussions

SITE CHARACTERIZATION

Results of soil health indicators must be interpreted among sites with similar context and climatic characteristics. When monitoring soil health regularly on the same site, this information may provide interpretation on the effect of current soil management practices or land use on certain soil health indicator and on how newly adopted soil management practices would improve the indictor.

Site characterizations over the 15 sites were summarized below:

- Main crops: The three main crops being grown are tomatoes, eggplants, and English cabbage. Crops are being grown in all seasons of the year but the peak time in vegetable production in August/September which is around the mid-point of the dry/cool season.

- Crop rotation: Most farmers rotate between 2 or more kinds of vegetables. About 25% of the farmers rotated vegetables with cereals such as maize.
- Erosion: High number of the respondents (88% of the responses) reported that their land had suffered from flooding in the last 5 years. It indicated that farm land has high risk of erosion and loss of top fertile soils. 11% of farmers had tried to improve drainage of their field.
- Tillage: The most common form of land preparation was the use of animals and a disc plough or harrow. Farmers reported a wide range of depth for tillage, such as 11 – 15 cm (38% of farmers), 16 – 20 cm (18% of farmers), or 20 – 30 cm (20% of farmers). Tillage is mainly done just before planting.
- Crop residue: Most of the time crop residue is ploughed back into the soil (49%), although 40% of responses indicated that they remove the residue from the field.
- Fertilizer application: The use of fertilizer appeared to be very common and almost all of the farmers used some form of fertilizers. Urea and NPK were the most commonly used (each about 45%) with extremely limited use of other fertilizers such as animal manure (6%) or compost (1%). Typically, fertilizers were applied just once around planting.
- Pesticide use: Nearly all (93%) farmers used some form of commercial pesticide. There was, however, much greater variation on which pesticides were used. For tomatoes, the most commonly used was Superguard. For eggplants, Confidor and Sunchloroprid were more popular. For English cabbage the most commonly used pesticide was Prevathon. Unfortunately, there were not enough responses for each of the different crops to draw meaningful conclusions regarding the rate of application. Only very few farmers reported using non-synthetic pesticides to control pests.
- Irrigation: The most common irrigation method across all four crops was by using a bucket or watering can. The sprinklers is the third most common method overall and particularly for eggplants.
- Constraints to production: Clearly flooding is a key concern for vegetable producers. For eggplant, English cabbage and tomatoes, the greatest constraint is severe pest damage.
- Soil texture: 70% of farmers did not know about their soil texture, only 24% farmers considered their soils were sandy loam and 6% as loam.

SITE REPORTING SHEET

Specific reporting sheet could be produced for individual farm. Information of Farm S10 was used as an example to show a format to compile results to produce a farm-specific report (Table 3). Farmers and extension officers could store such sheets to monitor soil health status over time.

Table 3. Reporting sheet of Farm S10.

Site Description		DATE : Sept, 2012
Soil ID : 10	Land owner : Arun Lal	
Geographic Location	Longitude : 18°3'25.31" S	Latitude : 178°32'19.69" E
Field or site location	Koronivia settlement	
Soil Information		
Soil Series	n.a.	
Slope %	mild slope (< 15˚)	
Mean Annual Temperature*	27.9 ℃ (highest temperature: 30 ℃ in Jan.~Feb; and lowest temperature: 26℃ in July~Sept.)	
Mean Annual Precipitation*	3060 mm annually, with dry season (< 200 mm monthly) from June to Sept.	
Past Management		
Cropping System (Rotation/cover crop, etc)	bele-tomato-eggplant or beans-eggplant (3 major vegetables: tomato, eggplant, beans)	
Fertilizers/Pesticides (N inputs, pesticide use, etc)	Fertilization: Tomato: chicken manures with the rate of N-P-K=48.8-26-30 kg/ha Eggplant: applied chicken manure 4 times/year Beans: no fertilizer Pesticide used: Supergua	
Tillage/Residue Cover (Type, depth, frequency, timing, % cover, etc)	Tractor/harrow till to 15cm at land preparation; animal/scarifier tillage mid-crop stage; Tractor/disc plough till to 15cm after harvest	
Irrigation (method, amount and timing, etc)	No irrigation for all crops	
Other	Crop residues were left in the field	
Unusual Events (Floods, fires, land-leveling)	Flooding in 2012; drainage improved in2011	

SOIL HEALTH SURVEY REPORT**				
Indicators		Value	Score	Constraints/ Recommendation
PHYSICAL	Infiltration Test (cm/hr)	6.76	1	
	Bulk Density (g/cm3)	1.23	2	
	Physical observation:(a+b+c+d)/4		1	
	a. Soil Texture	clay loam	1	

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	b. Penetration (cm)	16.67	1	
	c. Soil compaction	compact	0	Soil compaction/targeted deep tillage, deep-rooted cover crops, avoid traffic on wet soils
	d. Root Growth	lateral	1	
	Soil stability test	slaking,no dispersion	1	
BIOLOGICAL	Earthworm (No/30 cm^3 soil)	9.67	1	
	Soil respiration test	3.83	2	
	Organic matter (%)	2.70	1	
	Labile carbon (ppm)	580	1	
CHEMICAL	pH (Soil:Water = 1:5)	6.43	2	
	EC (mS/cm)	0.04	0	Low soluble nutrients/proper and balanced fertilization, add organic composts, leguminous rotation crops
	Nitrate test (NO_3-N,kg/ha)	3.75	0	Low nutrient availability/proper and balanced fertilization, add N-rich organic composts, leguminous rotation crops
OVERALL SOIL HEALTH SCORE:			11.2	**Medium class**

*Monthly average weather data assessed on http://www.weather2travel.com/climate-guides/fiji/ for Suva where is close to Koronivia.

**The report format from Cornell Soil Health Assessment Training Manual (2) is modified and adopted for Table 3b.

SUMMARY OF SOIL HEALTH INDICATOR

SOIL INFILTRATION TEST

Infiltration rate was high (>50 cm/hr) in 4 out of 15 soil samples. There is a need to improve water retention ability in these Farms. Two Farms had moderately rapid infiltration rate (6 cm/hr) (Fig. 3). After conversion (Table 6), scores of all farms were 1 or 2, which indicated there is no slow infiltration constraint. However, great variations among 3 replications of several farms were observed, which might be due to poor uniformity of top soils or survey sampling errors. The test should be repeated during dry season.

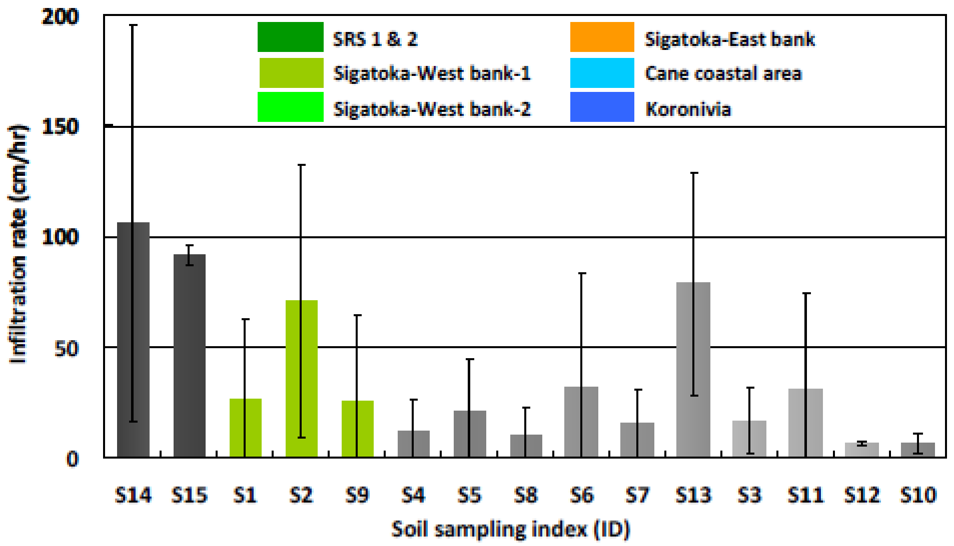

Fig 3. Soil infiltration rate at each farm surveyed, Fiji, 2012.

BULK DENSITY TEST

As presented in Fig. 4, 2 farms had bulk density higher than 1.5. To interpret the bulk density properly, it should be combined with soil texture data. Based on USDA soil quality test kit guide, data are converted to score and indicated as effect on root growth. Results show that 11 out of15 soil samples are ideal for root growth, while 3 samples are moderately ideal for root growth (S3, S11, S13), and only S6 may restrict root growth.

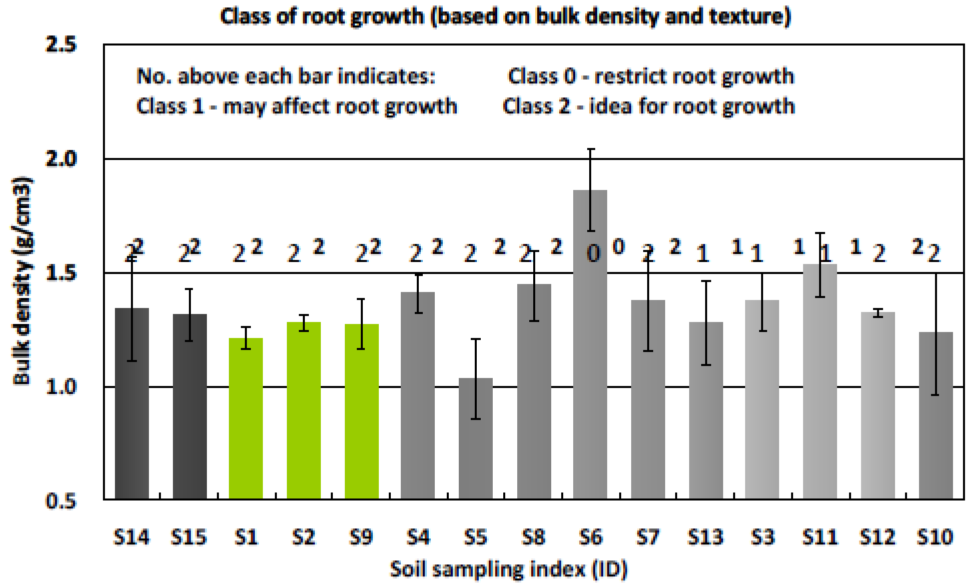

Fig 4. Soil bulk density at each farm surveyed with score relating to root growth

SOIL PHYSICAL OBSERVATIONS

Physical observations included texture by feel, penetration test, compaction layers, and root growth. Soil structure observation was not conducted, because all field surveyed were ploughed and could not be observed for their structures. In terms of soil texture, only 2 farms (S13, S3) have texture constraint (Table 4). Soils in Cane Coastal Area have higher lateral penetration distance and loose layer. Overall scores of the four observations are either"1" or "2". Variations among 3 replications of several farms were observed.

Table 4. Results of physical observations in soils at each farm surveyed, Fiji, 2012

Indicator / Soil ID	4. Physical observation				
	4 (a) Texture (by feel method)*	4 (b) Penetration (lateral, cm)	4 (c) Compaction layers*	4 (d) Root growth*	Score for 4 (4a+4b+4c+4d)/4)
S14	clay loam	10.7	loose, medium, compact	tap & lateral	1
S15	clay loam	10.0	compact	tap & lateral	1
S1	loam, clay loam, clay	23.8	compact	lateral	1
S2	clay loam	16.7	loose, medium	tap & lateral	2
S9	silty clay loam, clay loam, silty clay	14.0	compact, loose	tap & lateral	1

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S4	clay loam	18.7	compact	lateral	1
S5	clay loam, clay	24.3	loose	tap & lateral, lateral	2
S8	clay loam	11.3	compact	lateral, tap & lateral	1
S6	sandy loam	23.3	compact, loose	tap & lateral, lateral	2
S7	sandy loam, sandy clay loam	17.3	compact	tap & lateral, lateral	1
S13	clay loam, clay	18.7	loose, compact	tap & lateral, lateral	1
S3	clay loam, clay	32.7	compact	lateral	1
S11	sandy clay loam	24.7	loose, compact	tap & lateral, lateral	1
S12	sandy clay loam	34.7	loose, compact	lateral	1
S10	clay loam	16.7	compact	lateral	1

* data separated with comma indicated the different observations across 3 replications at each farm

SOIL STABILITY TEST

Slaking occurred for all soils surveyed (Table 5) indicated that aggregates were not strong enough to withstand the stresses of rapid water uptake. These implied that all soils tested may form crusting after heavy rain. On the other hand, dispersion test showed that 13 out of 15 soils had Type 4 (no dispersion using moist aggregates) results, indicating the aggregate structure of these soils are fairly stable. The soil should not crust and should have good rates of water entry, but may still have erosion risk. Only soils in Sigatoka Research Station showed Type 3 dispersion in moist aggregates. This means that the 2 sites have potential for crusting and erosion and have score of "0".

Table 5. Results of soil stability test at each farm surveyed, Fiji, 2012

Soil ID No.	Soil Stability test	
	Slake test	Dispersion type*
S14	slaking	3
S15	slaking	3
S1	slaking	4
S2	slaking	4
S9	slaking	4
S4	slaking	4
S5	slaking	4
S8	slaking	4
S6	slaking	4

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S7	slaking	4
S13	slaking	4
S3	slaking	4
S11	slaking	4, 3, 4
S12	slaking	4
S10	slaking	4

*** Type 1-Dispersion: use air dry aggregates, after 24 hours complete dispersion**
Type 2-Dispersion: use air dry aggregates, after 24 hours incomplete dispersion
Type 3-Dispersion: use moist aggregates, after 24 hours have dispersion
Type 4-Dispersion: use moist aggregates, after 24 hours have no dispersion

EARTHWORM TEST

All farm tested had poor earthworm counts (Fig. 5). No or less than 2 earthworms per m^2 was observed on 9 soil samples and only 3 soils (S3, S11 and S10) had 5-10 earthworms. Farm S10 which received chicken manure regularly had the highest earthworm number. Converted scores data (Table 6) showed only 4 farms had score of "1".

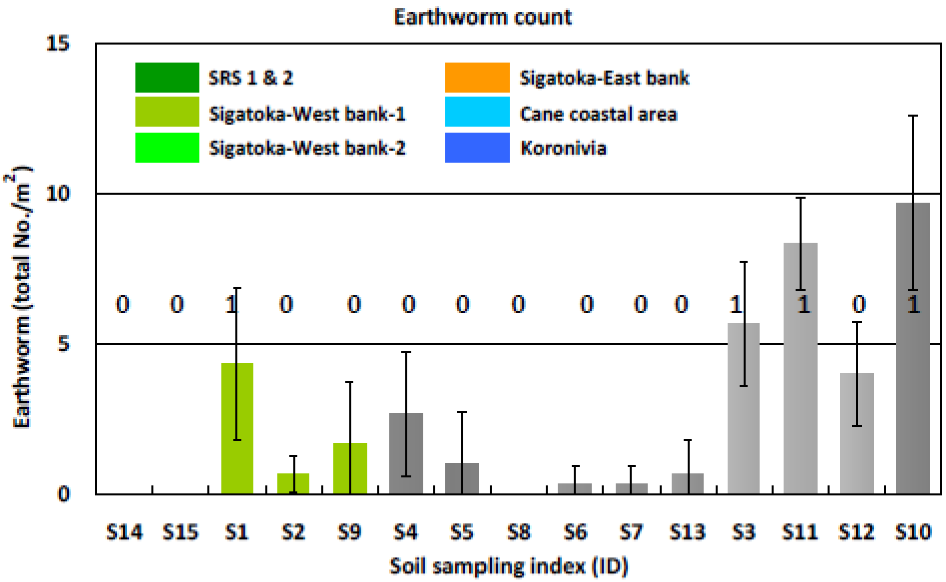

Fig 5. Numbers of earthworm counts at each farm surveyed with score relating to soil health

SOIL RESPIRATION TEST – SOLVITA SOIL LIFE KIT

Results of soil respiration (Solvita) test indicated that 14 out of 15 soils had moderately low soil microbial activity, only 1 soil (S10 with score 2) had idea soil microbial activity (Fig.

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6). This result was in agreement with the earthworm count, indicating that continuous addition of organic manure is the key contribution factor to improve biological property of soils. This test showed that microbial activity needs to be improved greatly in almost all survey soils. Due to lack of the test kit, this test was not measured for S15 which was very near location of S14.

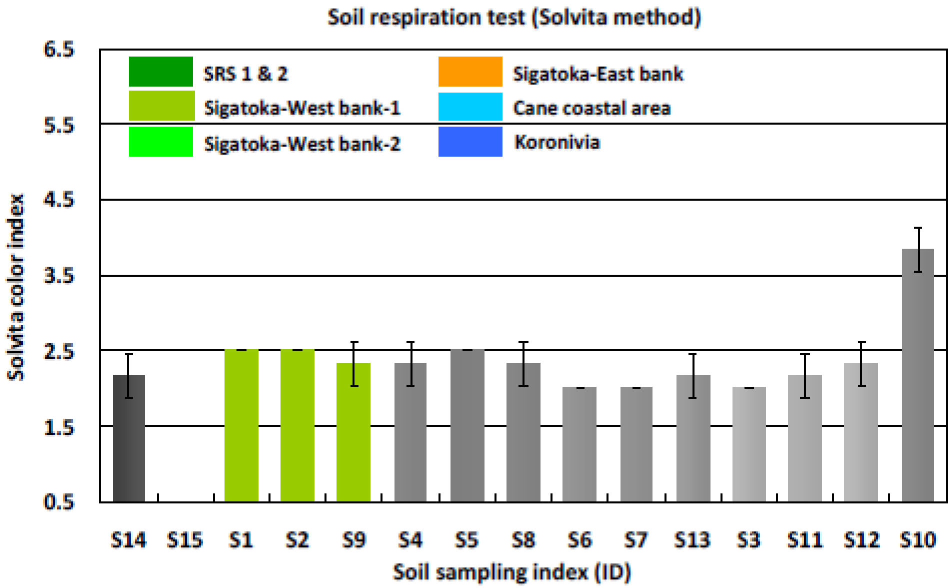

Fig 6. Results of soil respiration (Solvita) test at each farm surveyed. (S15 was not determined)

ORGANIC CARBON TEST

For interpretation of organic matter contents, the scoring function developed by Cornell soil health team was adopted; interpretations were adjusted for each of the major coarse, medium and fine soil textural classes. The original scale of 0-30 is considered as score "0", 30-70 to as "1" and 70-100 as "2" (Appendix 1).

Seven out of 15 soils had score of "0", 6 soils had score "1" and only 2 soils were optimal in organic matter contents (Table 6 and Fig.7). Overall, 13 soils were low in organic matter contents.

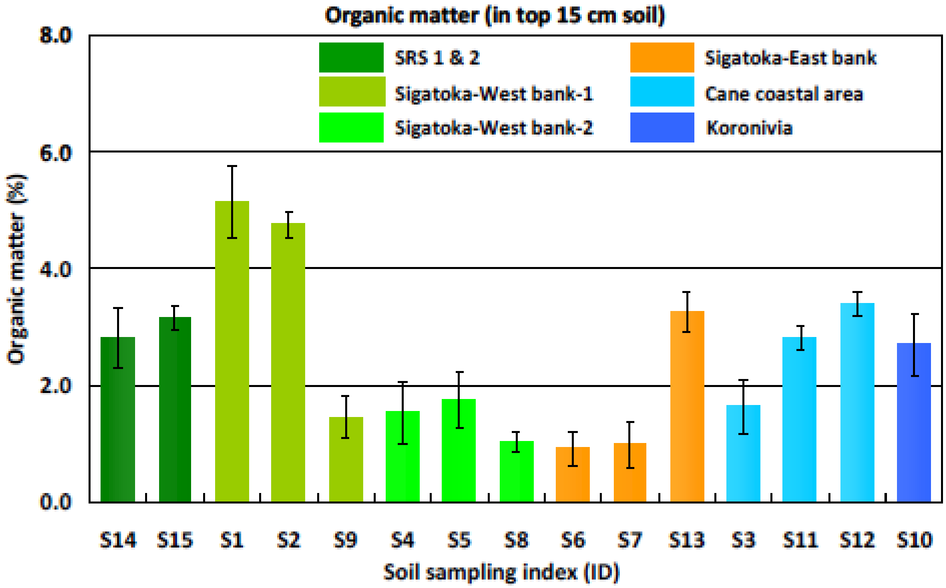

Fig 7. Soil organic matter contents in top 15 cm soils of each farm surveyed

LABILE (ACTIVE) CARBON TEST

Similar to organic matter, the scoring function developed by Cornell soil health team was adopted to interpret the results and adjusted for three major coarse, medium and fine soil textural classes. The original scale of 0-30 was considered as score "0", 30-70 as score "1" and 70-100 as score "2" (Appendix 1).

The condition of labile carbon contents in soils was slightly better than organic matter contents. Results showed 5 out of 15 soils had score "0" with insufficient labile C, 8 soils had score "1", and only 2 soils had adequate labile C contents (Table 6 and Fig. 8).

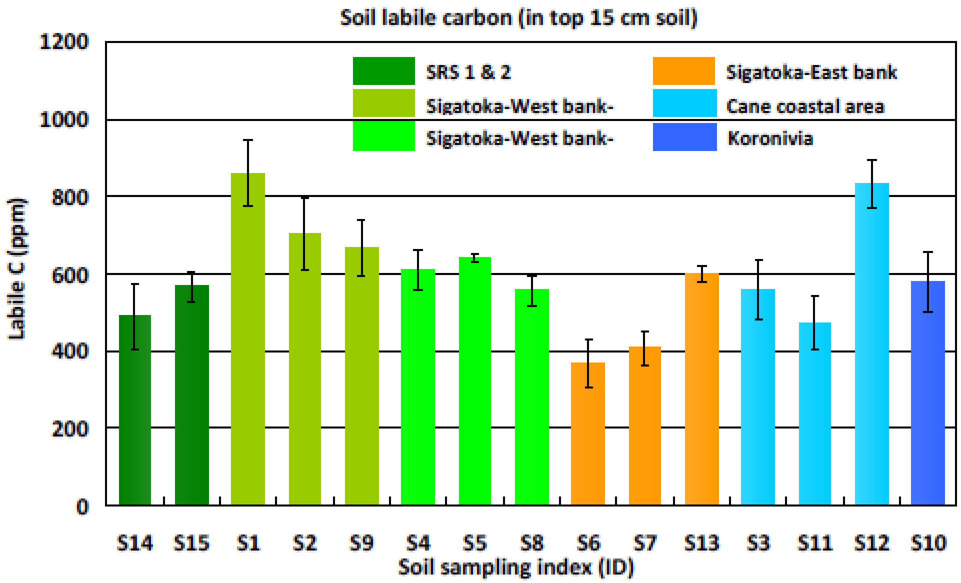

Fig 8. Soil labile carbon contents in top 15 cm soils of each farm surveyed

SOIL pH TEST

For interpretation of soil pH, scoring function developed by Cornell soil health team was adopted, which was an optimum category of scoring curve. Simply judging from the original pH values (Fig. 9), it was clearly indicated that most soils (13 out of 15) tested had optimal pH values, except 1 soil had pH greater than 7.7 (S15, Sigatoka Research Station). Improvement should be made on this soil to avoid micronutrient deficiency. Two soils located in coastal areas had acidic pH values of 6.1 and 5.8. Although S3 had pH value of 6.1 with score "2", it is better to raise pH by liming to 6.5 for better crop growth, soil health and sustainability.

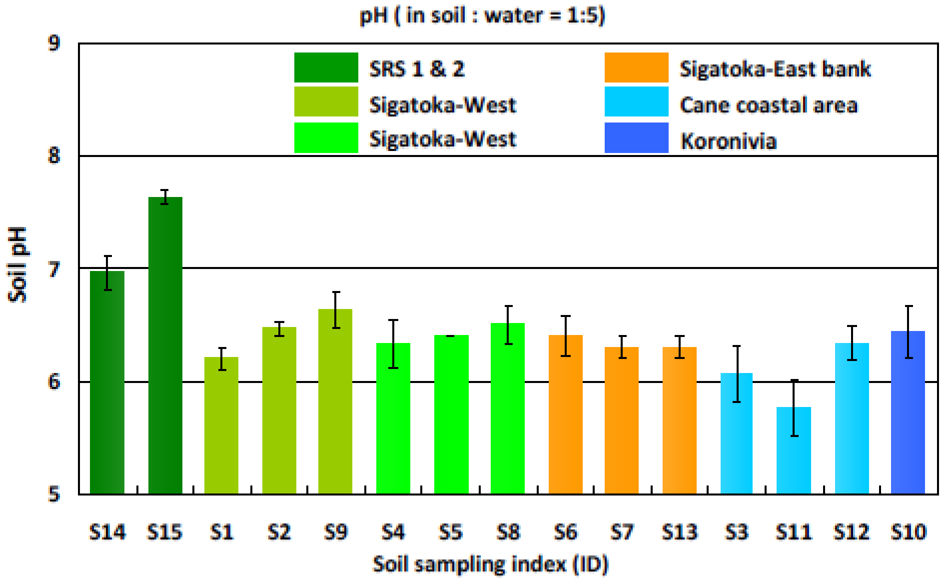

Fig 9. Soil pH in each farm surveyed

SOIL Electrical Conductivity (EC) TEST

Soil EC test can be used to measure if a soil has salinity constraint. Excess salts in soil can be detrimental to plant health and root growth. $EC_{1:5}$ (m*S*/cm) with value <0.07 (10-20% clay) to <0.09 (20-40%clay) is rated as "very low" soil salinity class (Tolmie P.E. and Biggs A.J.W. (9)). All soils surveyed have very low EC values (Fig. 10), indicating that there were no salinity constraints in the farms surveyed.

On the contrary, EC can also be an indicator for soil soluble nutrients. Results indicated there were very low soluble nutrients readily available for plant in all surveyed soils, indicating low soil fertility. Soil fertility needs to be improved in all soils tested.

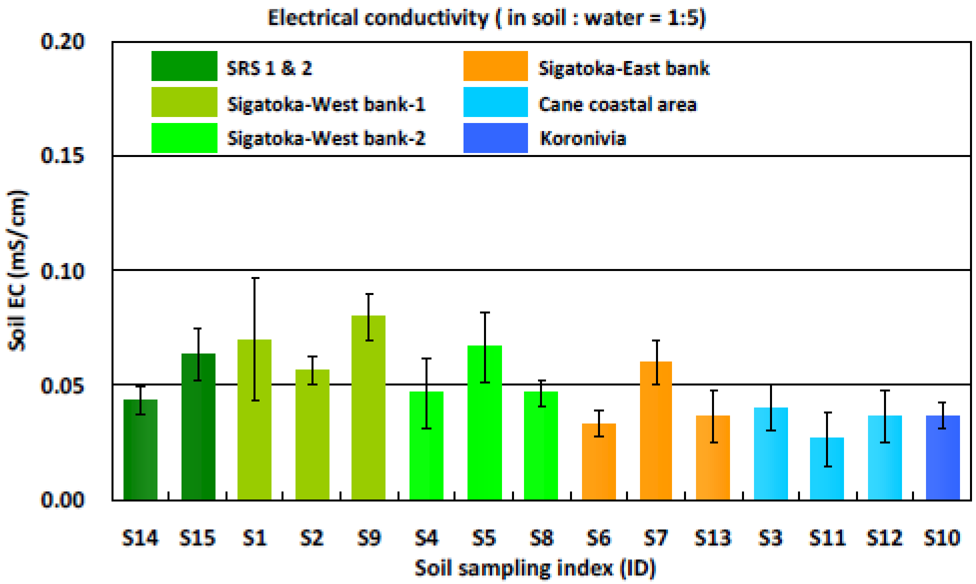

Fig 10. Soil EC (Electrical Conductivity) in each farm surveyed, Fiji, 2012

SOIL NITRATE TEST

Soil nitrate concentration is a good measurement of readily available nitrogen to the plants. In this test, data had been converted to kg/ha of NO_3-N, which is equivalent to readily available amount of N fertilizers to the crops. All soils tested had nitrate-N contents less than 10 kg/ha except S1 which had a slightly higher content (12.5 kg/ha NO_3-N, Fig. 11). The result was in agreement with the finding of low EC values. In the "Crop Farmers Guide" published by MPI, the inorganic fertilizer rates recommended for several major vegetables appeared to be too low if farmers do not apply together with poultry manure. Based on soil health survey, efficient and integrated balanced fertilizer management will be recommended to Fiji farmers for the improvement of soil health as well as crop productivity.

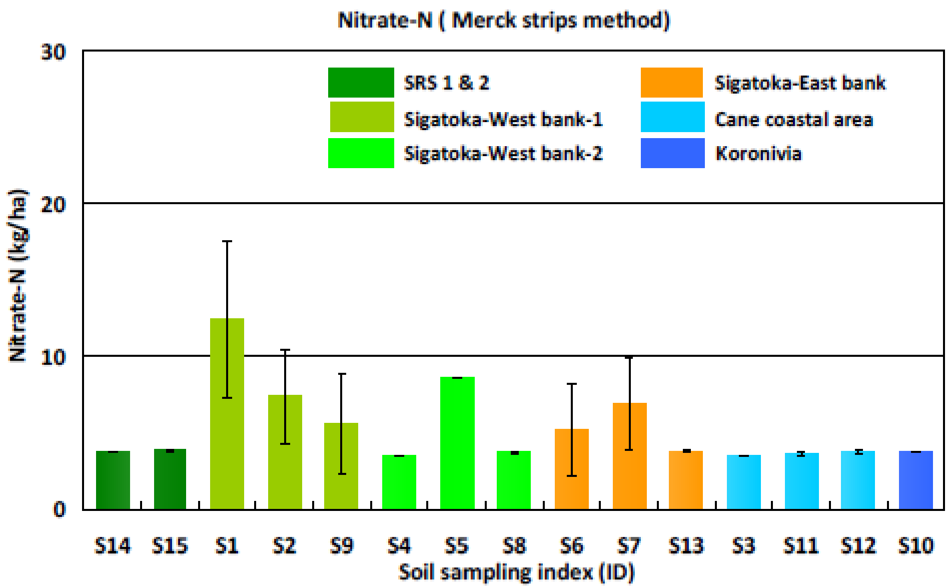

Fig 11. Soil nitrate-N in soils of each farm surveyed, Fiji, 2012

Conclusions

Scores of 11 indicators obtained from individual farm surveyed are summarized in Table 6. An overall score and soil health class are assigned to each farm. Soil health classes for overall scores are defined as: "Poor" for total score "0-7"; 'Moderate" for score of "8-15" and 'Good" for score of "16-22".

All farms surveyed had the "Moderate" soil health class. However, based on overall scores, farms located in "Sigatoka-west bank-1" (S1, S2), one farm in "Coastal area" (S12) and one farm in "Koronivia" (S10) had higher scores. While farms S6 and S7 which located in "Sigatoka-east bank" had the lowest overall scores (7.6 and 8.3, respectively). Judging from the scores of each indicator, it is clear that all farms surveyed had less concerns on physical indicators. However, low fertility and organic matter that resulted in low score of earthworm and respiration tests is a common constraint. Soil texture is an "inherent" property which is difficult to be changed. However, through adding organic matter, proper tillage and soil management, crop rotation and cover crops, soil structure and bulk density can be greatly improved.   Chemical indicators are "dynamic" soil properties which can be easily improved through proper fertilization management; consequently, biological indictors can be enhanced gradually. Recommendations of soil management relevant to each soil constraints are summarized in Table 7. For achieving better soil health status and soil sustainability, it is strongly suggested that all farmers can adopt recommended soil management practices to improve soil health status of their farms.

Table 6. Summary of soil health scores of each indicator and individual farm*

Indicators \ Soil ID	S14	S15	S1	S2	S9	S4	S5	S8	S6	S7	S13	S3	S11	S12	S10
	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score
Physical															
2. Infiltration test	2	2	1	2	1	1	1	1	1	1	2	2	1	1	1
3. Bulk Density	2	2	2	2	2	2	2	2	0	2	1	1	1	2	2
4. Physical observation: ((4a+4b+4c+4d)/4)**	1	1	1	2	1	1	2	1	2	1	1	1	1	1	1
4 (a) Texture	1	1	1	1	1	1	1	1	2	1	0	0	1	1	1
4 (b) Penetration	1	1	2	1	1	1	2	1	2	1	2	2	2	2	1
4 (c) Compaction	1	0	0	2	1	0	2	0	1	0	1	0	1	1	0
4 (d) Root growth	2	2	1	2	2	1	2	2	1	2	2	1	1	1	1
5. Stability test	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Biological															
6. Earthworm test	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1
7. Respiration (Solvita) test	1	n.d.	1	1	1	1	1	1	1	1	1	1	1	1	2
8. Organic matter	1	1	2	2	0	0	0	0	0	0	1	0	1	1	1
9. Labile carbon	0	1	2	1	1	1	1	1	0	0	0	0	1	2	1
Chemical															
10. Soil pH test	2	1	2	2	2	2	2	2	2	2	2	2	1	2	2
11. Soil EC test	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12. Nitrate (NO_3-N) test	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall soil health score	8	8	13	13	10	9	10	9	8	8	10	8	9	12	11
Soil health class***	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

* Note: the Scores were average of three replicated samples. Rounded values were presented.

** Score of No. 4, Physical observation are the average values of 4a, 4b, 4c and 4d indicators. Only score 4 (not scores of 4a, 4b, 4c and 4d) are included in overall score.
n.d. : not determined, S15 has 1 of total score less than S14 due to this test was missing.
***Soil health classes for overall scores are defined as: "Poor" for score 0-7; 'Moderate" as score of 8-15 and 'Good" as score of 16-22.

Table 7. Summary of soil constraints identified in the survey and recommendations of management strategies for improving those constraints

Indicator	Score (or values)	No. of field identified*	Soil constraints	Recommendation
Physical				
2. Infiltration test (cm/hr)	0 (or score "1" with rate < 1.5 cm/hr)	1 site out of 45	Slow infiltration, compaction, poor structure and drainage	proper/reduced tillage, build up organic matter, incorporate crop residues, cover crops/green manure
3. Bulk Density (BD, g/cm3)	0 (or score "1" with BD >1.5-1.7)	4 sites out of 45	High bulk density, compaction, poor aeration and drainage, restrict root growth	add fresh organic matter, improve structure (add organic amendments), shallowed-rooted cover crops, reduce compaction (limited mechanical soil loosening), proper tillage, crop rotation
4. Physical observation: (4a Soil Texture)	0 (sand or sandy clay or clay)	7 sites out of 45	Heavy texture, poor aeration and drainage, restrict root growth	improve structure (add organic amendments), cover crops/crop rotation, proper tillage, top soil incorporated with sand or clay
4. Physical observation: (4c Soil compaction)	0	29 sites out of 45	Soil Compaction	targeted deep tillage, deep-rooted cover crops, avoid/reduced equipment loads/traffic on wet soils
5. Stability test	0	7 sites out of 45	Low aggregates stability	build up organic matter (add fresh organic materials), shallow-rooted cover/rotation crops, manure, reduce tillage,
Biological				

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6. Earthworm test	0	34 sites out of 45	low earth worm count	build up soil organic matter (add organic composts or manures, cover crops, crop rotation)
7. Respiration (Solvita) test	1	39 sites out of 42	Low microbial activity, declines in organic matter	build up soil organic matter (add organic composts or manures, cover crops, crop rotation)
8. Organic matter (OM, %)	0	23 sites out of 45	Low OM, low microbial activity	add stable organic matter (compost, crop residues high in lignin, biochar); cover and rotation crops
9. Labile carbon (LC, ppm)	0	13 sites out of 45	Low labile C, low microbial activity	add fresh organic composts or manures, shallow-rooted cover crops, crop rotation, green manures
Chemical				
10. pH test	0 (pH < 5.7, or > 7.7)	2 sites out of 45	Low pH or high pH	apply lime/biochar (low pH) or apply acid-fertilizer/plant-based meal-type organic fertilizer, proper application of poultry manure (high pH)
11. EC test	0	45 sites out of 45	Low EC, low soluble nutrients	proper and balanced fertilization, add organic composts/manure, leguminous cover/rotation crops
12. NO_3-N test (NO_3-N, kg/ha)	0	44 sites out of 45	Low nutrient (NO_3-N) availability	proper and balanced fertilization, add N-rich organic composts/manure, leguminous cover/rotation crops

* Soil health surveys were conducted in a total of 15 farms, and each farm had three sampling sites, which composed of total 45 sampling sites.

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Appendix 1

Definition of scores of soil health indicators

Scores for infiltration test*

classes	rate (cm/hr)	Score
Very rapid	> 51	2
Rapid	15.2-51	2
Moderately rapid	5.1-15.2	1
Moderate	1.5-5.1	1
Moderately slow	0.5-1.5	1
Slow	0.2-0.5	0
Very slow	0.004-0.2	0
Impermeable	< 0.004	0

*Source: USDA. 2001. Soil Quality Test Kit Guide. Page 56, Table 3

Score for Bulk density (adjusted by soil Texture)*

Soil texture	Ideal bulk densities (g/cm^3)	Bulk densities that may affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.30	1.60	> 1.75
Silt loams, silt clay loams	< 1.40	1.55	> 1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	< 1.10	1.49	> 1.58
Clays (> 45% clay)	< 1.10	1.39	> 1.47
Score	2	1	0

*Source: USDA. 2001. Soil Quality Test Kit Guide. Page 57, Table 4

Score for Soil Physical Observation Indicators

Indicator	Score 0 (Poor)	Score 1 (Medium)	Score 2 (Good)
4a. Soil texture by feel method[1]	Sand, loamy sand, sandy clay, silty clay, or clay.	Clay loam, silty clay loam, or sandy clay loam.	Sandy loam, or silt loam.
4b. Soil lateral penetration test[2]	Penetrates to less than 5 cm	Penetrates more than 5 but less than 20 cm	Penetrates to 20 cm or more
4c. Compaction[3]	Compact layers	Medium firm soils	Loose soils
4d. Root growth[3]	Few lateral roots	More lateral roots	Tap and lateral roots
Physical observation, Total score = (4a+4b+4c+4d)/4			

[1] Source: USDA, Natural Resources Conservation, Soil Indicator Scorecard. 2001.

[2] Source: Australia. Northern Rivers Soil Health Card for Vegetables. 2008.

[3] Source: Soil Health Assessment Users Guide. Queensland University of Technology, Australia, 2007.

Score for Soil Stability Indicator*

Indicator	Score 0 (Poor)	Score 1 (Medium)	Score 2 (Good)
Soil stability test*	Aggregate slakes and disperses	Aggregate slakes but no dispersion	Aggregate has no slaking and dispersion

* Source: Soil Health Assessment Users Guide. Queensland University of Technology, Australia, 2007

Score for Biological Indicators

Indicator	Score 0 (Poor)	Score 1 (Medium)	Score 2 (Good)
Soil earthworm test[X]	Low No. (0~3) of earthworms in shovelful of top 30cm of soil, no casts or holes	Moderate No. (>4~10) of earthworms, few casts or holes	Many earthworms in top 30 cm of soil (>10 or more), lots of casts and holes
Soil respiration test (Solvita kit)[Y]	Solvita Index 0~1 or >5; soil shows little biological activity and depletes in organic matter	Solvita Index 1~2.5; soil is in moderate biological activity and declines in organic matter	Solvita Index 2.5~3.5 or 3.5~4; soil has idea biological activity and receives adequate organic matter

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Soil organic matter content[Z]	OM <2.2%, <2.8% and <3.5% for coarse, medium and fine texture soils, respectively	OM in 2.2-3.9%, 2.8-4.2% and 3.5-4.8% for coarse, medium and fine texture soils, respectively	OM >3.9%, >4.2% and >4.8% for coarse, medium and fine texture soils, respectively
Soil labile carbon (LC) content[Z]	LC <430, <520 and <630 ppm for coarse, medium and fine texture soils, respectively	LC in 430-680, 520-720 and 630-860 ppm for coarse, medium and fine texture soils, respectively	LC >680, >720 and >860 ppm for coarse, medium and fine texture soils, respectively

[X] Source: Maryland Soil Quality Assessment Book, Univ. of Maryland. USA.

[Y] Source: Solvita Guideline for Soil Respiration Test, Woods End Laboratories, USA. 2011.

[Z] Source: Cornell Soil Health Assessment Training Manual. Ed.2. Cornell university, 2009.

Score for Chemical Indicators

Indicator	Score 0 (Poor)	Score 1 (Medium)	Score 2 (Good)
Soil pH test[1]	pH < 5.7, or > 7.7	pH 5.7~6, or 7.5~7.7	pH 6-7.5
Soil EC test[2] (dS/m = mS/cm)*	$EC_{1:5}$ >0.93 (10-20% clay) to >1.21 (20-40%clay), as "extreme high" salinity class.	$EC_{1:5}$ =0.15~0.34 (10-20% clay) to 0.19~0.45 (20-40%clay), as "medium" salinity class.	$EC_{1:5}$ <0.07 (10-20% clay) to <0.09 (20-40%clay), as "very low" salinity class.
Soil nitrate-N test[3]	Low soil nitrate level, NO_3-N <25 kg/ha	Moderate soil nitrate level, NO_3-N at 25-50 kg/ha	Satisfactory soil nitrate level, NO_3-N >50 kg/ha

[1] Source: Cornell Soil Health Assessment Training Manual. Ed.2. Cornell university, 2009.

[2] Source: Tolmie P.E. and Biggs A.J.W. 2000. Soil salinity. In: Understanding Soils and Soil Data and Land Management Issues. P. 12-1~12-23.

[3] Source: Soil Quality Test Kit Guide. USDA Soil Quality Institute. 2001. Page 68.

*If $EC_{1:5}$ is too low, indicating a very low level of soil fertility, score "0" is assigned to this case.

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11.9 Appendix 9: Photo sheets from selected PHCs

S A M O A

SAVAII -SALAILUA PLANT HEALTH CLINIC

MAF | 2 FEBRUARY 2017

This plant clinic was held at Salailua MAF Station in Savaii, and organized by MAF. This place is located west of Savaii and 30 mins drive from Salelologa town area. A total of 13 farmers participated, 2 women and 11 men. None were part of a farmer group. All 13 farmers brought samples. Some key problems presented were bacterial wilt of tomatoes, LCM of cabbages, cracks in breadfruit fruit, banana bunchy top, fungal leaf spots of cucumber, rots of young pumpkin fruit, taro corms and cocoa pods. The farmers were referred to the Agriculture Store when the Plant Health Doctors give them recommendations on pesticides.

The plant doctors were: Aleni Uelese, Tommy Tuuamalii, Saipele Komiti, Maposua Akenese, Hemi Siaosi, Seluia Afaese, Anita Fainuu and Lilyhana Leauanae (2 from Upolu and the rest of staff are from Savaii).

Prepared and reported by MAF, Samoa. For more information, contact Tommy Tuuamalii, Head of Advisory Division (phone 20607); Email: tommy.tuuamalii@maf.gov.ws. Plant clinics are held as part of the *Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of high value horticulture.* A project funded by ACIAR. *Plant clinics are held as part of the ICM/IPM sub-regional project, funded by ACIAR.*

Solomon Islands

Guadalcanal

Honiara Central Market Plant Health Clinic

MAL Extension Division | 9 March 2017

This plant clinic was held at Honiara Central Market, and organized by the Ministry of Agriculture and Livestock, Extension Division. It was held as part of the training on Plant Health Clinics (6-10 March 2017) provided by the ACIAR ICM/IPM project detailed below. Forty-four farmers (18 women and 26 men) came to the clinic and five brought samples, taro, Chinese cabbage leaves and seedlings, eggplant, and lettuce.

The plant doctors were James Tahopa (SFO Western), Jerine Lano (AFO Temoto), Ennie Nare (AFO Malaita), Frank Odona (SFO Isabel), Margaret Kiko (FO Extension Honiara), Caroline Harunari (AFO Honiara), Helina Barasa (AFO Extension Honiara), Rosemary Ha'adota (SFO Training & Information Honiara), Betty Luisah (AFO Central), Aldrine Sogati (SFO Choiseul), Regina Bilo (AFO Guadalcanal), Charles Kuarangi (SFO Makira). Aldrine Sogati was Clinic Manager.

Some of the key problems presented were Papuana beetle on taro, DBM on Chinese cabbage, whitefly on capsicum and tomato, gummy stem blight on watermelon, ?anthracnose on capsicum.

Prepared and reported by MAL. For more information contact Rosemary (phone number, email) from the MAL Extension Division. Photos by Manu Mua, SPC, Suva, Fiji. Plant clinics are held as part of the a sub-regional IPM project Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of high-value crop production, with support from the Australian Centre for International Agricultural Research, Canberra.

SAMOA

ALEIPATA Upolu

ULUTOGIA PLANT CLINIC

Ministry of Agriculture & Fisheries | 21 April 2017

This plant clinic was held at Ulutogia, Atua District, Upolu (21 April 2017). It was organised by the MAF Crops Division. The village is located on the eastern side of Upolu opposite the Aleipata Islands. By road it is about 60 kms from Apia. Nineteen farmers participated in the clinic (12 women and 7 men) and 22 samples were received.

Some of the important problems were: mites on tomatoes and capsicum, caterpillar on Chinese cabbages, a rot of pumpkin and breadfruits, damping off of young Chinese seedlings in greenhouse, and black pod diseases of cocoa.

The plant doctors were from the Crops and Advisory Divisions: Fiu Sailo, Loise Nuulua, Peniamina Aiomanu, Christian Tone, Bernadette Tuietufuga, Mu Vaamainuu, and Aleni Uelese (Senior Research Officer).

Prepared and reported by the Ministry of Agriculture & Fisheries. For more information, contact Aleni Uelese. Mob: 7654846, Email: aleni.uelese@maf.gov.ws, or Bernadette Tuietufuga, Email: bernadette.tuiletufuga@maf.gov.ws. Photos by Aleni Uelese. Plant clinics are held as part of a sub-regional IPM project, ***Strengthening integrated crop management research in the Pacific Islands in support of sustainable intensification of high value crop production***, with support from the Australian Centre for International Agricultural Research, Canberra.

This Plant Health Clinic was held at the Sigatoka Research Station, Nacocolevu. It was organized by the Ministry of Agriculture in collaboration with the Pacific Community, as part of the Field Day for Rio Gold Tomato Awareness; an activity of the recent ACIAR ICM/IPM project, detailed below. More than 100 farmers attended the Field Day but only 14 (7% female) took part in the Clinic, as there were other simultaneous activities (Rio Gold Field Visit; Capsicum Organoleptic Test). Some brought more than one sample to a total of 25. Problems on Capsicum (Sunscald), Cucumber (likely Thrips), Eggplant (Thrips & Flea beetles), Guava (Whiteflies), Long Bean (Pod Borer & Leaf Miner), Papaya (probably Crown rot), Plantain (possibly viral infection) Sweet potato (Scab), Tomato (Wilting) and Watermelon (likely Gummy Stem Blight). The plant Doctors were: Makereta Rasuka, Anare Caucau, Toloi Vasuidreketi, Dr. Visoni Timote, Milika Saunivalu, Meri Tupou, Adi Vika Tuiverata, Arieta Tuiverata, Varanisese Naiobasali, Asma Bibi, Takala Talacakau, and Mani Mua. The Clinic was 2 hours long from 11:30 am. Makereta Rasuka was the Manager.

Prepared and Reported by the Ministry of Agriculture. For more information, contact Makereta Rasuka, Nacocolevu. Mob: 9316880 Email: makeretarasuka@yahoo.com; Photos by Anare Caucau and Mani Mua. Plant Health Clinics are held as part of a sub-regional ICM/IPM project – *Strengthening integrated crop management research in the Pacific Islands in Support of sustainable intensification of high value vegetable crop production*, with support from the Australian Centre for International Agricultural Research, Canberra.

SOLOMON ISLANDS

Central Market Honiara

MAL Extension Division | 22 June 2017

This plant clinic was held at Honiara Central Market, organized by the Extension Division of the Ministry of Agriculture and Livestock. Thirty-four farmers (14 female and 20 male) attended the clinic but only 1 sample was received. The main problems reported at the clinic were: gummy stem blight on water melon, Papuana beetle on taro, shoot borers on sliperi kabis , Giant African snail, and caterpillars on cabbages.

Plant doctors: Clement Totu (FO); Carolyn Harunari (AFO); Rosemary Alabas (SFO), Florence Kwai (AFO); Josephine (AFO); Wilson Kofela (AFO); Julian Tota (AFO); Matilda Tineia (AFO); Magreth Kiko (AFO); Moses Losi (AFO).

Prepared and reported by MAL. For more information contact Rosemary Ha'adota (Phone: 7997059/25031, Email: rosemary.Alabae@sig.gov.sb). Photos by Clement Totu and Rosemary Ha'adota. Plant clinics are held as part of the sub-regional ICM/IPM Project Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of High-value crop production, with support from the Australia Centre for international Agriculture Research, Canberra.

Solomon Islands Guadalcanal

Vutu Plant Health Clinic

MAL Extension Division | 4 July 2017

This plant clinic was held at Vutu village, Northeast Guadalcanal, organized by the Extension Division, Ministry of Agriculture and Livestock. It was held so that extension officers could practice being "plant doctors". Thirty-Five farmers attended (23 women and 12 men) and they brought 47 samples: Chinese cabbage, taro, banana, eggplant, pawpaw, guava, capsicum, sweetpotato, beans, cocoa, mandarin, betel nut and sliperi kabis.

The plant doctors were Moses Losi (FO), Caroline Harunari (AFO Honiara), Margret Kiko (SFO Extension Honiara), Rosemary Alabas (CFO), Clement Totu (PFO), Florence Kwai (AFO), Josephine (AFO), Julian Tora (AFO), Matilda Tineia (FA), and Wilson Kofela (AFO). The first four had attended training in March 2017 (Grahame Jackson); the others received a 3-day training prior to the clinic (Pita Tikai).

Problems presented were; cluster caterpillars and Papuan beetle on taro, whitefly on capsicum, shoot borer on sliperi kabis, citrus scab on orange, scab moth on banana, cabbage caterpillar on Chinese cabbage, fruit fly on guava, black pod on cocoa, blossom-end rot and cracking on tomato, leaf folder on sweet potato, and giant African snail.

Prepared and reported by MAL. For more information contact Rosemary Ha'adota (phone: 7997059/2503; email: rosemary.Alabae@sig.gov.sb). Photos by Wilson Kofela. Plant clinics are held as part of the sub-regional ICM/IPM Project Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of High-value crop production, with support from the Australian Centre for international Agriculture Research, Canberra.

S A M O A

XX (major administrative area e.g.)

ALEISA PLANT CLINIC

MAF | 1 September 2016

This plant clinic was held at Aleisa, and organized by MAF. The Aleisa clinic is located 12 km S from Apia town in the low hills. 28 farmers participated at the clinic (25 women and 3 men from the women's vegetable growing group, and 50 samples were received. Some of the key problems presented were bacterial wilt, frog eye spot and broad mite of peppers; LCM of cabbages; stem rot of lettuce; fruit piercing moth of orange; fungal leaf spots of cucumber; scale/mealbugs on soursop; and sunscald on tomatoes.

The plant doctors were: Aleni Ulese; Iva Tauai; Sailo Pao; Fililagi Tolefaoa; Bernadette Siisiialafia; Theresa Wright; Leafa Ah-Kee; Anita Fiumu; Loise Nuulua; Mu Vaamainuu; Peniamima Aiomanu; Lilihana Leauanuae; Christian Tone Talamau; Enoka Keniseli; Vincent Vaiso; Tommy Tuuamalii; Ulupano Pati.

Prepared and reported by MAF, Samoa. For more information, contact Tommy Tuuamalii, Head of Advisory Division (phone 20607); Email: tommy.tuuamalii@maf.gov.ws. Plant clinics are held as part of the *Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of high value horticulture.* A project funded by ACIAR. *Plant clinics are held as part of the ICM/IPM sub-regional project, funded by ACIAR.*

FIJI

WESTERN AGRICULTURE SHOW Nadi

Ministry of Agriculture | 8-10 November 2017

This Plant Health Clinic was conducted in conjunction with the Ministry of Agriculture – Western Agriculture Show, 8-10 November 2017, in Nadi. There theme of the show was "climate smart agriculture". There were about 20 farmers, a third of whom were women. Only eight farmers brought samples; in all there were forty problems to diagnose.

There were problems on eggplant (nutritional, whiteflies, mealybugs, flea beetles, thrips and mites), chilli (anthracnose of fruit, mites and thrips), cabbage (DBM and LCM larvae), tomato (shoot borer, blight diseases, fruit borer, nutritional, bacterial wilt and root rot), watermelon (gummy stem blight), taro (dalo beetle), coconut (rhinoceros beetle), Guava/mango (whiteflies, mealybugs), citrus (nutritional), weeds (African tulip tree), capsicum (mites and thrips), cowpea (pod borer), long bean (pod borer), flowers (mealybugs) and vutu/tavola (flea beetles).

The plant doctors were: Toloi Vasuidreketi, Unaisi Tuaraganivalu, Anare Caucau, Makereta Rasuka, and Milika Saunivalu. Tolo was the clinic manager.

Prepared and Reported by the Ministry of Agriculture. For more information, contact Makereta Rasuka, Nacocolevu. Mob: 9316880 Email: makeretarasuka@yahoo.com; Plant Health Clinics are held as part of a sub-regional ICM/IPM project – ***Strengthening integrated crop management research in the Pacific Islands in Support of sustainable intensification of high value vegetable crop production***, with support from the Australian Centre for International Agricultural Research, Canberra.

11.10 Appendix 10: Susceptibility of diamondback moth field populations to insecticides in Fiji, Samoa and Tonga. [All comparisons vs susceptible Waite Strain].

Table 11.10.1 Diamondback moth susceptibility to insecticides. Sigatoka Valley, Viti Levu 2013, Fiji. (UV=Upper Valley, MV= Mid valley, LV= Lower valley)

Population	Insecticide	Generation tested	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
UV	Deltamethrin	F_1	280	0.59(0.307-1.093)	1.21 (±0.214)	8.39(22)	12.43(1.68-92.05)
MV	Deltamethrin	F_1	280	0.97(0.59-1.49)	1.97(±0.29)	17.22(22)	20.26(2.92-140.59)
LV	Deltamethrin	F_3	280	1.57(0.82-2.99)	1.044(±0.177)*	15.837 (22)	30.03(4.79-187.91)
UV	Indoxacarb	F_1	280	0.24(0.05-0.45)	2.24(±0.49)	24.38(22)	1.48(0.13-5.22)
MV	Indoxacarb	F_1	280	1.94(1.21-2.83)	2.997(±0.501)	8.679(22)	16.88(4.49-63.32)
LV	Indoxacarb	F_3	280	4.69(2.3-8.932)	1.064(±0.178)	9.922(22)	25.79(9.37-70.99)
UV	Lufenuron	F_1	280	0.28(0.09-0.51)	1.88(±0.39)	9.82(18)	3.01(0.37-24.46)
MV	Lufenuron	F_1	280	1.71(0.91-2.77)	1.98(±0.33)	12.05(22)	18.41(2.43-139.18)
LV	Lufenuron	F_3	280	0.18(0.001-0.59)	0.934(±0.240)	15.20(22)	1.25(0.185-8.41)
UV	Bt	F_1	280	0.0005(0.0001-0.001)	3.37(±1.09)	14.24(18)	0.79(0.29-2.18)
MV	Bt	F_1	280	0.001(0.0006-0.0017)	2.56(±0.57)	10.94(18)	1.86(0.078-4.42)
LV	Bt	F_3	280	0.001(0.001-0.0023)	3.18(±0.58-5.47)	19.32(18)	3.68(1.57-8.64)
UV	Prevathon	F_1	280	0.016(0.00-0.06)	3.49(±0.099)	14.86(18)	1.88(0.91-3.89)
MV	Prevathon	F_1	280	0.36(0.22-0.53)	2.574(±0.417)	8.178(18)	5.974(2.34-15.27)
LV	Prevathon	F_3	280	1.04(0.65-1.60)	1.631(±0.22)	18.42(22)	12.86(5.52-29.97)
Waite	Deltamethrin	F_8	280	0.05(0.00-0.16)	0.943 (±0.31)	7.49(17)	-
	Deltamethrin	F_9	280	0.052(0.01-0.18)	0.84(±0.22)	8.85(21)	-
Waite	Indoxacarb	F_8	280	0.16(0.02-0.34)	1.941(±0.52)	9.24(17)	-
	Indoxacarb	F_9	280	0.18(0.04-0.33)	2.44(±0.62)	11.34(18)	-
Waite	Lufenuron	F_8	280	0.09(0.001-0.33)	1.142(±0.36)	8.12(17)	-
	Lufenuron	F_9	280	0.15(0.030-0.29)	2.10(±0.51-4.15)	7.05(17)	-
Waite	Bt	F_8	280	0.0006 (0.0002-0.001)	2.214(±0.56)	6.46(18)	-
	Bt	F_9	280	0.0004(0.0001-0.0008)	2.47(±0.702)	17.45(18)	-
	Prevathon	F_8	280	0.08(0.04-0.134)	2.54(±0.0.56)	11.30(18)	-
	Prevathon	F_9	280	0.08(0.02-0.14)	0.329(±0.705)	14.93(18)	-

Table 11.10.2 Diamondback moth susceptibility to insecticides. Vanua Levu, Fiji 2013

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
Bulileka	Bt	F_1	280	0.008(0.004-0.011)	3.6(±0.88)	11 (22)	2.9(0.8-10)
Bulileka	Match	F_1	280	0.12(0.009-0.34)	1.35(±0.33)	7(22)	4.4(0.2-93)
Bulileka	Prevathon	F_3	280	0.89(0.51-1.34)	2.77(±0.51)	13(22)	3.5(1.8-6.8)
Bulileka	Steward	F1	280	13.94(9.01-19.71)	3.67(±0.75)	11(22)	77(29-205)
Bulileka	Suncis	F1	280	0.96(0.38-1.91)	1.33(±0.25)	23(22)	18(5.3-61)
Korotari	Bt	F1	280	0.004(0.001-0.007)	3.35(±1.07)	14(22)	1.64(0.4-6.8)
Korotari	Match	F1	280	0.46(0.0-0.12)	1.72(±0.54)	12(22)	1.7(0.06-47)
Korotari	Prevathon	F1	280	0.49(0.87-2.25)	2.75(±0.45)	24(22)	5.9(2.3-11)
Korotari	Steward	F1	280	0.025(0.0-0.12)	1.21(±0.36)	9(22)	0.14(0.01-1.7)
Korotari	Suncis	F1	280	0.02(0.001-0.012)	1.57(±0.42)	11(22)	0.38(0.06-2.6)
Waite	Bt	F22	280	0.003(0.0-0.005)	2.89(±1.02)	13(22)	-
Waite	Match	F22	280	0.27(0.0-0.14)	1.14(±0.37)	14(18)	-
Waite	Prevathon	F22	280	0.25(0.15-0.38)	2.34(±1.37)	10(22)	-
Waite	Steward	F22	280	0.18(0.048-0.37)	1.59(±0.32)	13(22)	-
Waite	Suncis	F22	280	0.05(0.01-0.11)	2.47(±0.3)	16(21)	-

Table 11.10.3 Diamondback moth susceptibility to insecticides. Viti Levu and Vanua Levu, Fiji, 2014

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
Bulileka	Bt	F_1	280	0.008(0.004-0.011)	3.6(±0.88)	11 (22)	2.9(0.8-10)
Bulileka	Match	F_1	280	0.12(0.009-0.34)	1.35(±0.33)	7(22)	4.4(0.2-93)
Bulileka	Prevathon	F_3	280	0.89(0.51-1.34)	2.77(±0.51)	13(22)	3.5(1.8-6.8)
Bulileka	Steward	F1	280	13.94(9.01-19.71)	3.67(±0.75)	11(22)	77(29-205)
Bulileka	Suncis	F1	280	0.96(0.38-1.91)	1.33(±0.25)	23(22)	18(5.3-61)
Korotari	Bt	F1	280	0.004(0.001-0.007)	3.35(±1.07)	14(22)	1.64(0.4-6.8)
Korotari	Match	F1	280	0.46(0.0-0.12)	1.72(±0.54)	12(22)	1.7(0.06-47)
Korotari	Prevathon	F1	280	0.49(0.87-2.25)	2.75(±0.45)	24(22)	5.9(2.3-11)
Korotari	Steward	F1	280	0.025(0.0-0.12)	1.21(±0.36)	9(22)	0.14(0.01-1.7)
Korotari	Suncis	F1	280	0.02(0.001-0.012)	1.57(±0.42)	11(22)	0.38(0.06-2.6)
Waite	Bt	F22	280	0.003(0.0-0.005)	2.89(±1.02)	13(22)	-
Waite	Match	F22	280	0.27(0.0-0.14)	1.14(±0.37)	14(18)	-
Waite	Prevathon	F22	280	0.25(0.15-0.38)	2.34(±1.37)	10(22)	-
Waite	Steward	F22	280	0.18(0.048-0.37)	1.59(±0.32)	13(22)	-
Waite	Suncis	F22	280	0.05(0.01-0.11)	2.47(±0.3)	16(21)	-

Table 11.10.4 Diamondback moth susceptibility to insecticides. Viti Levu, Fiji 2015.

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
East Bank	Bt	F_3	280	0.002 (0.001-0.003)	1.64(±0.33)	14(18)	4.3(1.8-10.2)
East Bank	Match	F_3	280	0.381(0.175-0.621)	2.19(±0.40)	8(22)	3.4(0.9-12.0)
East Bank	Multiguard	F_3	280	0.037(0.019-0.062)	1.89(±0.335)	13(22)	3.7(1.5-9.3)
East Bank	Prevathon	F_3	280	0.605(0.313-1.0)	1.59(±0.254)	12(21)	2.8(1.4-5.6)
East Bank	Steward	F_3	280	1.11(0.578-1.78)	2.12(±0.364)	13(22)	1.8(0.9-3.5)
West bank	Bt	F_3	280	0.0006 (0.0002-0.001)	2.14(±0.449)	13(22)	1.4(0.5-1.5)
West Bank	Match	F_3	280	0.343(0.124-0.635)	1.5(±0.262)	9(22)	2.8(0.7-10.6)
West Bank	Multiguard	F_3	280	0.019 (0.008-0.03)	1.82(±0.311)	9(22)	1.9(0.8-4.9)
West Bank	Prevathon	F_3	280	0.547 (0.364-0.579)	3.27(±0.53)	16(21)	2.6(1.5-4.4)
West Bank	Steward	F_3	280	0.486 (0.267-0.746)	2.29(±0.378)	11(22)	0.8(0.4-1.5)
Waite	Bt	F_{74}	280	0.0005 (0.0001-0.0008)	2.71 (±0.682)	32(21)	-
Waite	Match	F_{74}	280	0.112((0.014-0.261)	1.69(±0.415)	9(18)	-
Waite	Multiguard	F_{74}	280	0.01(0.004-0.017)	1.98(±0.35)	12(22)	-
Waite	Prevathon	F_{74}	280	0.214 (0.134-0.320)	2.41(±0.354)	7(22)	-
Waite	Steward	F_{74}	280	0.624 (0.38-0.92)	2.11(±0.306)	18(21)	-

Table 11.10.5 Diamondback moth susceptibility to insecticides. Viti Levu and Vanua Levu 2016

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
Korotari	Bt	F_2	280	0.0006(0.0003-0.0009)	4.01(±1.15)	6(18)	0.5(0.06-0.3)
Korotari	Match	F_2	280	0.12 (0.02-0.26)	1.69(±0.37)	8(22)	0.96 (0.19-4.9)
Korotari	Multiguard	F_2	280	0.003(0.00-0.01)	1.24 (±0.28)	8(22)	0.16(0.03-0.79)
Korotari	Prevathon	F_2	280	0.41(0.19-0.73)	1.2(±0.19)	10(22)	1.55(0.69-3.46)
Korotari	Steward	F_2	280	0.73(0.37-1.22)	1.44(±0.22)	14(22)	1.3(0.59-2.79)
Sigatoka	Bt	F_2	280	0.001(0.0005-0.002)	2.22(±0.41)	11(22)	0.23(0.09-0.56)
Sigatoka	Match	F_2	280	0.64(0.24-1.19)	1.39(±0.25)	14(22)	5.3(1.3-21)
Sigatoka	Multiguard	F_2	280	0.03(0.01-0.05)	1.2(±0.20)	20(22)	1.5(0.6-3.6)
Sigatoka	Prevathon	F_2	280	0.18(0.06-0.33)	1.2(±0.22)	11(22)	0.66(0.3-1.6)
Sigatoka	Steward	F_2	280	1.0(0.5-1.7)	1.3(±0.20)	10(22)	1.7(0.8-3.8)
Waite	Bt	F_{103}	280	0.0004(0.0001-0.0007)	2.73(±0.74)	13(22)	-
Waite	Match	F_{103}	280	0.12(0.01-0.28)	1.87(±0.48)	6(18)	-
Waite	Multiguard	F_{103}	280	0.02 (0.01-0.03)	2.0(±0.34)	10(22)	-
Waite	Prevathon	F_{103}	280	0.27(0.15-0.41)	1.84(±0.27)	10(22)	-
Waite	Steward	F_{103}	280	0.57(0.31-0.9)	1.76(±0.27)	12(21)	-

Table 11.10.6 Diamondback moth susceptibility to insecticides. Viti Levu, Fiji, 2017

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
East Bank	Bt	F_2	280	0.001(0.000-0.002)	1.9(±0.33)	9.3(22)	2.2(0.9-5.2)
East Bank	Match	F_2	280	1.4(0.78-2.29)	1.8(±0.27)	8.8(22)	5.8(2.0-16.8)
East Bank	Multiguard	F_2	280	0.1(0.05-0.17)	1.87(±0.32)	8.6(22)	27.6(6.0-13)
East Bank	Prevathon	F_2	280	0.41(0.19-0.73)	1.2(±0.19)	7.8(22)	0.6(0.3-1.5)
East Bank	Steward	F_2	280	0.84(0.38-1.49)	1.4(±0.24)	10.9(22)	3.0(1.0-9.1)
West Bank	Bt	F_3	280	0.0012(0.000-0.002)	1.9(±0.33)	9.3(22)	2.2(0.9-5.3)
West Bank	Match	F_3	280	0.31(0.12-0.54)	1.5(±0.27)	13.1(22)	1.3(0.4-4.2)
West Bank	Multiguard	F_3	280	0.047(0.03-0.08)	1.58(±0.23)	11(22)	12(2.7-57)
West Bank	Prevathon	F_3	280	0.43(0.26-0.66)	1.75(±0.24)	7.4(22)	0.7(0.3-1.4)
West Bank	Steward	F_3	280	0.57(0.29-0.93)	1.63(±0.24)	8.8(22)	2(0.7-5.8)
Waite	Bt	F_{130}	280	0.0005(0.0002-0009)	2.0(±0.45)	9.6(22)	-
Waite	Match	F_{130}	280	0.24(0.06-0.50)	1.5(±0.31)	9.8(22)	-
Waite	Multiguard	F_{130}	280	0.004(0.00-0.01)	1.3(±0.31)	8.7(22)	-
Waite	Prevathon	F_{130}	280	0.64(0.33-1.08)	1.5(±0.25)	0.64(0.34)	-
Waite	Steward	F_{130}	280	0.28(0.08-0.56)	1.4(±0.26)	15(22)	-

Table 11.10.7 Diamondback moth susceptibility to insecticides. Samoa, 2013

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
Aukuso	Attack	F_1	280	0.008(0.004-0.011)	2.4(±0.51-08)	17 (22)	0.8(0.4-1.3)
Aukuso	Bt	F_1	280	0.003(0.0019-0.005)	2.34(±0.37)	16(22)	0.28(0.1—0.3)
Aukuso	Match	F_3	280	0.84(0.290-1.618)	1.84(±0.32)	31 (22)	2.24(0.9-5.50
Aukuso	Prevathon	F1	280	0.42(0.226-0.668)	2.232(±0.423)	15(18)	2.41(0.6-5.9)
JW	Attack	F1	280	0.027(0.018-0.04)	2.37(±0.397)	19(22)	2.52(1.7-3.8)
JW	Bt	F1	280	0.015(0.012-0.019)	4.17(±0.76)	16(22)	1.65(1.2-2.2)
JW	Match	F1	280	1.78(0.876-2.946)	1.90(±0.334)	14(22)	4.73(1.9-11.2)
JW	Prevathon	F1	280	0.84(0.519-1.26)	2.79(±0.491)	17(18)	1.99(1.0-3.9)
Nu'u	Attack	F1	280	0.022(0.016-0.03)	3.45(±0.55)	14(22)	1.62(1.1-2.3)
Nu'u	Bt	F1	280	0.012(0.01-0.014)	5.75(±1.26)	26(22)	1.13(0.9-1.4)
Nu'u	Match	F1	280	1.68(1.03-2.42)	3.28(±0.60)	10(22)	4.5(2.1-9.2)
Nu'u	Prevathon	F1	280	0.44(0.27-0.64)	3.6(±0.63)	19(18)	1.03(0.6-1.9)
Waite	Attack	F16	280	0.01(0.006-0.013)	4.7(±1.32)	27(21)	-
Waite	Bt	F16	280	0.001(0.001-0.002)	4.0(±0.68)	7(22)	-
Waite	Match	F16	280	0.37(0.075-0.734)	2.45(±0.559)	25(17)	-
Waite	Prevathon	F16	280	0.18(0.07-0.3)	2.02(±0.41)	14(18)	-
Waite	Attack	F16	280	0.011(0.008-0.013)	6.76(±1.89)	23(21)	-
Waite	Bt	F16	280	0.009(0.005-0.011)	5.54(±1.24)	30(22)	-
Waite	Match	F16	280	0.37(0.075-0.734)	2.45(±0.559)	25(170	-
Waite	Prevathon	F16	280	0.199(0.88-0.33)	2.54(±0.546)	17(18)	-
Waite	Attack	F16	280	0.014(0.01-0.019)	5.14(±1.24)	25(21)	-
Waite	Bt	F16	280	0.010(0.007-0.013)	5.16(±1.23)	43(22)	-
Waite	Match	F16	280	0.37(0.07-0.73)	2.45(±0.55)	14(22)	-
Waite	Prevathon	F16	280	0.04(0.02-0.67)	2.23(±0.42)	15(18)	-

Table 11.10.8 Diamondback moth susceptibility to insecticides. Samoa, 2015

Population[a]	Insecticide	Generation[b]	N[c]	LC_{50} (95% CI) [ppm] [d]	slope (±SE)[d]	χ^2 (df)	RR (95% CI) [d]
Aukuso	Bt	F_2	280	0.0006 (0.0003-0.009)	2.21 (±0.77)	11(22)	1.20
	Match	F_2	280	0.90 (0.18-0.93)	1.31 (±0.22)	8(22)	0.19
	Prevathon	F_2	280	0.34 (0.15-0.62)	1.21 (±0.24)	6(18)	2.43
	Attack	F_2	280	0.008 (0.004-0.011)	1.29 (±0.294	29 (22)	0.26
China	Bt	F_2	280	0.0019 (0.0013-0.0027)	2.25 (±0.30)	8(22)	3.80
	Match	F_2	280	6.32 (3.93-10.25)	1.48 (±0.203)	4(22)	1.37
	Prevathon	F_2	280	0.14 (0.07-0.23)	1.86 (±0.331)	6(18)	1
	Attack	F_2	280	0.034 (0.02-0.06)	1.33 (±0.27)	15(22)	1.10
Faleasiu	Bt	F_2	280	0.0013 (0.0009-0.002)	3.64 (±0.61)	7(22)	2.60
	Match	F_2	280	4.97 (2.34-10.3)	0.9 (±0.17)	8(22)	1.08
	Prevathon	F_2	280	0.08 (0.03-0.15)	1.9 (±0.38)	7(18)	0.57
	Attack	F_2	280	0.018 (0.013-0.025)	1.98 (±0.325)	12(22)	0.58
Tanumalala	Bt	F_2	208	0.004 (0.003-0.05	3.52 (±0.42)	17(22)	8.0
	Match	F_2	208	3.61 (2.07-6.02)	1.32 (0.19)	10(22)	0.78
	Prevathon	F_2	208	0.23 (0.10-0.41)	1.4 (±0.26)	7(18)	1.64
	Attack	F_2	280	0.01 (0.007-0.025)	2.15 (±0.45)	26(22)	0.32
Waite	Bt	F_{52}	280	0.0005 (0.0002-0.0008)	2.7 (±0.60)	9(21)	-
	Match	F_{52}	280	4.62 (2.9-7.4)	1.5 (±0.215)	4(21)	-
	Prevathon	F_{52}	280	0.14 (0.09-0.19)	3.4 (±0.58)	8(18)	-
	Attack	F_{52}	280	0.031 (0.021-0.049)	1.6 (±0.30)	17(21)	-

Table 11.10.9 Diamondback moth susceptibility to insecticides. Tonga, 2013

Population	Insecticide	Generation	n	LC50 (95% CI)	slope (±SE)[a]	χ^2 (df)	RR (95% CI)
Veitongo	Prevathon	F1	280	0.042(0.027-0.058)	3.46(±0.61)	16(18)	3.3(1.8-1.6)
Veitongo	Match	F1	280	0.031(0.003-0.074)	1.54(±0.41)	17(18)	0.8(0.2-3.8)
Veitongo	Steward	F1	280	0.11(0.46-0.32)	1.13(±0.32)	11(18)	2.4(0.89-6.4)
Veitongo	Suncis	F1	280	0.41(0.17-2.2)	1.09(±0.33)	9(18)	68(14-318)
Waite	Prevathon	F12	280	0.013(0.006-0.019)	3.89(±1.01))	6(18)	-
Waite	Match	F12	280	0.39(0.009-0.77)	1.79(±0.42)	14(18)	-
Waite	Steward	F12	280	0.04(0.023-0.076)	1.66(±0.35)	16(18)	-
Waite	Suncis	F12	280	0.006(0.001-0.014)	1.57(±0.42)	13(17)	-

Table 11.10.10 Diamondback moth susceptibility to insecticides. Tonga, 2014-2015

Population[a]	Insecticide	Generation[b]	N[c]	LC_{50} (95% CI) [ppm] [d]	slope (±SE)[d]	χ^2 (df)	RR (95% CI) [d]
Aukuso	Bt	F_2	280	0.0006 (0.0003-0.009)	2.21 (±0.77)	11(22)	1.20
	Match	F_2	280	0.90 (0.18-0.93)	1.31 (±0.22)	8(22)	0.19
	Prevathon	F_2	280	0.34 (0.15-0.62)	1.21 (±0.24)	6(18)	2.43
	Attack	F_2	280	0.008 (0.004-0.011)	1.29 (±0.294	29 (22)	0.26
China	Bt	F_2	280	0.0019 (0.0013-0.0027)	2.25 (±0.30)	8(22)	3.80
	Match	F_2	280	6.32 (3.93-10.25)	1.48 (±0.203)	4(22)	1.37
	Prevathon	F_2	280	0.14 (0.07-0.23)	1.86 (±0.331)	6(18)	1
	Attack	F_2	280	0.034 (0.02-0.06)	1.33 (±0.27)	15(22)	1.10
Faleasiu	Bt	F_2	280	0.0013 (0.0009-0.002)	3.64 (±0.61)	7(22)	2.60
	Match	F_2	280	4.97 (2.34-10.3)	0.9 (±0.17)	8(22)	1.08
	Prevathon	F_2	280	0.08 (0.03-0.15)	1.9 (±0.38)	7(18)	0.57
	Attack	F_2	280	0.018 (0.013-0.025)	1.98 (±0.325)	12(22)	0.58
Tanumalala	Bt	F_2	208	0.004 (0.003-0.05	3.52 (±0.42)	17(22)	8.0
	Match	F_2	208	3.61 (2.07-6.02)	1.32 (0.19)	10(22)	0.78
	Prevathon	F_2	208	0.23 (0.10-0.41)	1.4 (±0.26)	7(18)	1.64
	Attack	F_2	280	0.01 (0.007-0.025)	2.15 (±0.45)	26(22)	0.32
Waite	Bt	F_{52}	280	0.0005 (0.0002-0.0008)	2.7 (±0.60)	9(21)	-
	Match	F_{52}	280	4.62 (2.9-7.4)	1.5 (±0.215)	4(21)	-
	Prevathon	F_{52}	280	0.14 (0.09-0.19)	3.4 (±0.58)	8(18)	-
	Attack	F_{52}	280	0.031 (0.021-0.049)	1.6 (±0.30)	17(21)	-

Table 11.10.10 Diamondback moth susceptibility to insecticides. Tonga, 2014-2015 (cont)

Population[a] [date collected]	Insecticide	Generation[b]	N[c]	LC_{50} (95% CI) [ppm] [d]	slope (±SE)[d]	χ^2 (df)	RR (95% CI) [d]
Folaha	**Decis**	F_1	280	84.9 (25.9-1465)	0.93 (±0.22)	7(22)	**70 (12-398)**
[Sept 2014]	Steward	F_1	280	2.14 (1.52-2.98)	2.8 (±0.34)	22(22)	1.3 (0.7—2.4)
	Attack	F_1	280	0.023 (0.017-0.035)	4.15 (±0.55)	46(22)	0.01 (0.009-0.012)
	Match	F_1	280	2.87 (1.42-4.68)	2.30 (±0.42)	29(26)	3.5 (1.87-6.69)
	Prevathon	F_1	280	1.39 (1.0-1.84)	4.38 (±0.75)	10(22)	2.25 (1.5-13.4)
	Bt	F_1	280	0.69 (0.46-0.11)	2.86 (±0.33)	36(22)	2.83 (1.86-4.29)
Vaini [July 2015]	Bt	F_1	280	0.0008 (00003-0.001)	1.68 (±0.31)	22(22)	1
[Dec 2015]	Multigard	F_1	280	0.03 (0.003-0.075)	1.61 (±0.39)	9(21)	0.31 (0.07- 1.36)
	Steward	F_1	280	4.5 (2.89- 7.05)	2.26 (±0.27)	29(22)	2.7
	Match	F_1	280	0.36 (0.09- 0.77)	1.11 (±0.21)	17(21)	0.44
	Prevathon	F_1	280	2.59 (1.48- 4.01)	1.79 (±0.29)	19(22)	4.12
Waite	Decis	F_2	280	1.21 (0.72-1.99)	1.41 (±0.21)	16(21)	-
	Steward	F_2	280	1.66 (0.82-2.99)	1.36 (±0.21)	25(21)	-
	Attack	F_2	280	0.011 (0.009-0.012)	5.19 (±1.13)	9(22)	-
	Match	F_2	280	0.81 (0.53-1.19)	1.91 (±0.23)	24(25)	-
	Prevathon	F_2	280	0.62 (0.44-0.86)	3.09 (±0.39)	22(21)	-
	Bt	F_2	280	0.24 (0.16-0.35)	3.39 (±0.49)	31(22)	-
	Bt	F_{11}	280	0.0008 (0.0004-0.001)	6.04 (±2.10)	13(14)	-
	Multigard	F_x	280	0.09 (0.04-0.16)	2.27 (±0.45)	16(21)	-

[a] DBM larvae and pupae collected from farmers' fields; Waite is standard susceptible population

11.11 Appendix 11: Packaging of AgChem Bt and information leaflet on i) appropriate formulation and application of Bt and ii) the insecticide resistance management strategy. Information leaflet prepared by SPC and supplied with AgChem Bt by retailer (AgChem Fiji., Ltd.).

The AgChem BT product that has been promoted through the project is shown in Figure 1. Note the sticker that is packaged with the Bt wettable powder formulation (Figure 1 a) and the information on the insecticide resistance management strategy on the back of the package. Intsructions are provide in Fijian. Hindi and English (Figure 1 b)

Figure 1: AgChem Bt packaging. a) The Bt wettable powder and sticker are boxed together and sold as a single unit. b) Important safety and usage information is provided on the packaging in Fijian, Hindu and English.

Figure 2: Information leaflet supplied with all sales of AgChem Bt. Upper panel, information on Bt and its effective use, lower panel information on the insecticide resistance management (IRM) strategy

11.12 Appendix 12: Literature review of the host range of Trichogramma chilonis Ishii (Hymenoptera: Trichogrammatidae)- from Uelese et al., 2014.

Known Lepidopteran host range of *Trichogramma chilonis* based on published papers.

Family	Total records (% of total)	Species[a]
Arctiidae	3 (2)	*Amsacta moorei*[1], *Spilarctia obliqua*[1], *Spilosoma obliqua*[1]
Blastobasidae	1 (<1)	*Pseudohypatopa pulverea*[1]
Cossidae	1 (<1)	*Phragmataecia gummata*[1]
Crambidae	32 (22)	*Chilo auricilius*[1], *Chilo indicus*[1], *Chilo infuscatellus*[2], *Chilo partellus*[2], *Chilo sacchariphagus*[2], *Chilo simplex*[3], *Chilo suppressalis*[2], *Chilo venosatus*[2], *Cnaphalocrocis medinalis*[2], *Crocidolomia pavonana*[4], *Deanolis sublimbalis*[1], *Diaphania indica*[1], *Diatraea saccharalis*[1], *Diatraea* sp.[3], *Emmalocera depressella*[2], *Eoreuma loftini*[1], *Hymenia recurvalis*[2], *Leucinodes orbonalis*[5], *Marasmia patnalis*[1], *Marasmia exigua*[5], *Nacoleia octasema*[6], *Omiodes indicata*[1], *Ostrinia furnacalis*[7], *Ostrinia nubilale*[1], *Parapoynx stagnalis*[1], *Psara* sp. [1], *Scirpophaga incertulas*[1], *Scirpophaga intacta*[1], *Scirpophaga nivella*[1], *Scirpophaga excerptalis*[1], *Scirpophaga* sp.[2] *Tryporyza incertulas*[2]
Danaidae	1 (<1)	*Anosia chrysippus*[1]
Eupterotidae	1 (<1)	*Apha aequalis*[1]
Gelechiidae	3 (2)	*Pectinophora gossypiella*[1], *Phthorimaea operculella*[1], *Sitotroga cerealella*[1], *Boarmia variegata*[1]
Gracillariidae	1 (<1)	*Caloptilia* sp.[2]
Hesperiidae	3 (2)	*Parnara guttata*[1], *Pelopidas mathias*[2], *Udaspes folus*[8]
Hyblaeidae	1 (<1)	*Hyblaea puera*[1]
Lasiocampidae	2 (1)	*Dendrolimus punctatus*[1], *Gastropacha* sp.[1]
Lycaenidae	6 (4)	*Deudorix epijarbas*[1], *Jamides bochus formosanus*[8], *Lampides boeticus*[8], *Virachola isocrates*[1], *Virachola livia*[1], *Zizeeria maha argia*[5]
Lymantriidae	3 (2)	*Euproctis similis*[5], *Ivela auripes*[1], *Orgyia postica*[8]
Noctuidae	32 (22)	*Achaea janata*[2,10], *Anomis flava*[1], *Arcte coerulea*[2], *Asota ficus*[5], *Autographa nigrisigna*[5], *Busseola fusca*[1], *Chrysodeixis chalcites*[1], *Earias insulana*[1], *Earias* sp.[1], *Earias vittella*[1], *Eublemma amabilis*[1], *Eudocima fullonia*[9], *Helicoverpa armigera*[2], *Helicoverpa assulta*[2,5], *Helicoverpa zea*[10], *Heliothis* sp.[1], *Heliothis virescens*[1], *Mammestra brassicae*[5], *Naranga aenescens*[1], *Othreis* sp.[1], *Plusia nigrisigna*[1], *Plusia orichalcea*[1], *Rivula atimeta*[1], *Sesamia calamistis*[2], *Sesamia inferens*[2], *Spodoptera exigua*[1], *Spodoptera litura*[2,5], *Spodoptera mauritia*[10], *Spodoptera* sp.[1], *Tiracola plagiata*[2], *Tiracola plagiata*[1], *Trichoplusia ni*[2,8]
Notodontidae	1 (<1)	*Clostera cupreata*[1]
Nymphalidae	6 (3)	*Acraea issoria*[8], *Agraulis vanillae*[10], *Danaus chrysippus chrysippus*[5,8], *Danaus plexippus*[10], *Hipolimnas anomala*[1], *Hipolimnas bolina*[1], *Hypolimnas anomala*[7], *Hypolimnas bolina*[7], *Melanitis leda*[1]
Oecophoridae	1 (<1)	*Opisina arenosella*[1]
Papilionidae	5 (4)	*Papilio demoleus libanius*[8], *Papilio machaon hippocrates*[5], *Papilio polytes*[1], *Papilio protenor demetrius*[5], *Papilio xuthus*[5,10]
Pieridae	4 (3)	*Catopsilia pyranthe*[1], *Eurema* sp. [1], *Pieris brassicae*[1], *Pieris rapae*[1]
Plutellidae	1 (<1)	*Plutella xylostella*[5,8]
Pyralidae	4 (3)	*Corcyra cephalonica*[1], *Corcyra* sp.[1], *Ephestia kuehniella*[1], *Raphimetopus ablutellus*[1]
Saturniidae	6 (4)	*Antheraea pernyi*[1], *Antheraea yamamai*[1], *Dictyoploca japonica*[1], *Philosamia cynthia*[1], *Philosamia ricini*[1], *Samia cynthia*[1], *Acherontia styx*[1]
Sphingidae	9 (6)	*Agrius cingulata*[10], *Agrius convolvuli*[2,5,11], *Cephanodes hylas*[5], *Clanis bilineata*[1], *Daphnis nerii*[10,12], *Hippotion celerio*[13], *Macroglossum pyrrhostictum*[8,10], *Theretra silhetensis*[5]
Tortricidae	13 (9)	*Adoxophyes orana*[1], *Argyroploce schistaceana*[1], *Bactra* sp.[2], *Bactra truculenta*[1], *Cophoprora* sp.[1], *Cydia pomonella*[1], *Eucosma schistaceana*[1], *Homona coffearia*[2], *Laspeyresia koenigana*[1], *Leguminivora glycinivorella*[5], *Pandemis heparana*[1], *Peronea crocepepla*[1], *Tetramoera schistaceana*[2]

[a] Numbers refer to reference source.
[1] Polaszek (2010).
[2] Nagarkatti and Nagaraja (1971).
[3] Ishii (1941).
[4] Saucke et al. (2000).
[5] Honda et al. (2006).
[6] Hinckley (1964).
[7] Nafus (1993).
[8] Chan and Chou (2000).
[9] Cochereau (1977).
[10] Oatman et al. (1982).
[11] Nafus and Schreiner (1986a,b).
[12] Moore and Miller (2008).
[13] Doutt (1955).

11.13 Appendix 13: Promotion of Tomato Grafting in Solomon Islands

Heavy rains prove the value of grafting in the Solomon Islands

(left): Farmers **Michael** (*front and inset*) and **Dani** (*behind*) show their trial plot of grafted tomato plants. The grafted plants survived heavy rains and waterlogged soils to produce good quality fruit.
(right): Two students from the Suva Rural Training Centre east of Honiara in their school plot with vigorously growing grafted plants after continuous rainfall.

Grafting continues to gain traction among farmers in the Solomon Islands who are learning to use the method to produce tomato in the rainy season. Local AVRDC staff grafted 'Rose's Choice' tomato scions onto rootstocks of one of AVRDC's flood-tolerant eggplant lines, EG 195. A total of 238 grafted seedlings were distributed in March 2015 to interested farmers and two Rural Training Centers (RTCs) east of Honiara. Those who received these materials had attended a grafting training session conducted by AVRDC staff in November 2014.

The **Islanders Grassroot Farmers Association** of Burns Creek on the outskirts of Honiara received 106 grafted seedlings and grew them alongside non-grafted plants in the field. In mid-May, heavy rain fell continuously for more than three days, causing flooding and waterlogging. Less than a week after the heavy rainfall, the farmers observed that all their non-grafted tomato plants at fruiting stage had wilted, while the grafted plants survived. The women and men farmers of the association expressed satisfaction and excitement with this result, and are looking forward to selling the fruit produced by the grafted plants. With tomatoes typically in short supply in Honiara's central market during the wet season, the farmers expect to fetch good prices for their crop.

"All of us have been convinced that grafting can enable us to grow and produce tomatoes for the market during rainy season because we have seen how grafted plants survived in our very own plots," said **Michael Kalibiu**, the association's lead farmer. Other farmers in the Burns Creek area saw that the grafted plants survived, and now they have expressed interest in adopting the technology.

Only a few members of the association participated in the November training, so Kalibu requested AVRDC staff to conduct another training session for association members, especially women. He also seeks assistance with sourcing grafting materials, especially the rubber tubing used to join the graft, which is not available locally. The AVRDC team in the Solomons is delighted by the high level of enthusiasm demonstrated by members of the association, and will continue to promote grafting to interested farmers.