Australian Government

Australian Centre for International Agricultural Research

Final report

Project

Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia

project number	HORT/2010/089
date published	1/06/2019
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approved by	NA
final report number	FR2019-68
ISBN	978-1-925747-44-7
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

We wish to acknowledge those in the table below who contributed to the successful conduct of the project in both Bhutan and Australia. These collaborators are in addition to those detailed on the opening page of this document.

A special acknowledgement also goes to senior management of the Bhutan Ministry of Agriculture and Forests for their support and guidance over the term of project.

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2 Executive summary

The citrus growing community in Bhutan is estimated at 22,000 farmers. Citrus is the most important horticultural crop with 60% of the crop exported to Bangladesh and India. The average export return in AUD value was $11.4m pa from 2012 to 2016. This income is important to local farmers as it helps fund education costs for children and provides a ready source of money for general living expenses.

Citrus production has been affected by the introduction and spread of huanglongbing (HLB) disease as well as crop loss from Chinese citrus fruit fly and powdery mildew. Orchard activities such as canopy management, nutrition and irrigation have been a low priority for the majority of citrus farmers. The ACIAR project has aimed to provide citrus management skills to Bhutan Department of Agriculture (DoA) extension and research staff to assist them to educate and support local farming communities. This has involved training in Bhutan and Australia and these DoA officers then providing 'hands-on' training to other officers and the farming community. Training activities have involved extended visits to Australia for up to one month per officer and has focussed on specific areas such as irrigation design and management, laboratory diagnostics for HLB, nursery and citrus repository management, variety and rootstock development and biometric analysis and trial design. Training in Bhutan has been centred on seven demonstration farms as well as formal course delivery by Australian project staff and consultants on soil and water management, nursery water management and irrigation design.

Capacity development of local staff was also supported with attendance at International Citrus Congresses in Spain and Brazil along with representation at the International Citrus Nurseryman's Congress in Australia during 2017. Eight DoA project staff have undertaken post-graduate study in Australia with four having completed their studies (one MSc. and one PhD awarded, one PhD and one managerial award pending).

The project demonstrated the effectiveness of powdery mildew suppression with the use of regular sulphur sprays which could fit into an organic production system. Area wide Chinese citrus fruit fly management strategies of fruit collection and disposal along with bait spraying and trapping gave yield and economic benefits to the farmers involved in the pilot studies.

The yield and economic benefits of a gravity-fed drip irrigation system on a citrus demonstration farm has helped to stimulate a rapid expansion of irrigation for horticultural crops in Bhutan. The strategic application of water in periods of low rainfall during spring increased both fruit set, fruit weight and final yield at the orchard.

Bhutan staff updated the 'Production Guide for Mandarin Orchards in Bhutan', developed a booklet on 'Citrus Pests and Diseases Management' and wrote a Citrus nursery and repository management protocol. Current and former NSW DPI staff also published a 320 page 'Australian Mandarin Production Manual' in 2017.

The overall impact of the project was to develop a core group of DoA officers with citrus management skills that can be transferred to other extension and research staff and the farming community. The establishment of a National Citrus Repository (NCR) to hold high health status mother trees of Bhutanese mandarin selections and other introduced public citrus varieties is the basis for re-development of the local industry. Citrus productivity should continue to improve from the current 37kg per tree average (2012-2016) which is up from the four year average from 2008-2011 of 32kg per tree. Use of high health status budwood, rootstocks, canopy management, irrigation along with improved nutrition and management of major pests and diseases will continue to improve productivity.

3 Background

3.1 Bhutan

In Bhutan, agricultural production accounts for almost 20% percent of the Gross Domestic Product (GDP) and horticulture accounts for approximately 13 percent of the contribution of agriculture.

Citrus is one of the most important agricultural commodities to the economy of Bhutan providing valuable export earnings and income and employment for at least 60% of the population. Citrus is the most important horticultural crop in terms of area with 7,210 hectares (*average 2012-2016*) and annual production of 37,200 tonnes (*average 2012-2016*), and is grown in 16 of the 20 districts (Dzongkhags) of the country. The main citrus crop is mandarin (*Citrus reticulata*), with two cultivars predominating, 'Khasi' in the east and 'Sikkim' in the south-west districts.

There are over 22,000 citrus farms with tree numbers per grower varying from 3 to 900. Growers in excess of 50 trees are considered as commercial growers. Sixty-five percent of farms have less than 50 trees. Approximately 60% of the citrus crop is exported with an average AUD value *(2012-16)* of $11.4m pa, with the principal markets being Bangladesh and India.

A Scoping Study on the Bhutan citrus industry in 2005 identified potential to improve mandarin production through the introduction and demonstration of some basic agronomic practices to farmers. The impact of these practices on improving yield and therefore financial returns needed to be clearly demonstrated to farmers in order for them to more positively consider adopting improved production practices. The Bhutan citrus industry would benefit significantly from the earlier production afforded by the provision of high quality clean nursery trees that are budded onto suitable rootstocks.

In order to improve the overall productivity of the citrus industry in Bhutan, a four year ACIAR project (HORT/2005/142) 'Improving Mandarin production in Bhutan and Australia through the implementation of on-farm best management practices' was initiated in June 2007. This was followed by a second project (HORT/2010/089) 'Adapting Integrated Crop Management technologies to commercial citrus enterprises in Bhutan and Australia' which started in 2012 and completed in December 2017. The main partners in the project are NSW Department of Primary Industries, Western Sydney University, Bhutan Department of Agriculture (DoA) Horticulture Division, the National Plant Protection Centre (NPPC), the National Soil Services Centre (NSSC), the Agricultural Research & Development Centres (ARDCs), the National Postharvest Centre (NPHC), District Extension Services and National Seed Centre (NSC).

The aim of the current project was to build and expand on some of the key issues identified in the first project as being critical to maintaining and improving citrus production in Bhutan. The main foci are on securing Bhutan's citrus germplasm source, improving nursery tree production practices, improving knowledge and management for the key citrus pests and diseases, demonstrating citrus production practices, and disseminating information. The project also aimed to develop the citrus knowledge of key local staff through in-country training, a group study tour to Australia, extended DoA officer training in Australia, attendance at international citrus congresses and support for post graduate study in Australia. This expertise has enabled a core of experienced citrus staff to assist and manage the on-going development of citrus production in Bhutan. This was achieved by Department of Agriculture extension and research staff improving their citrus production skills through training and passing this knowledge onto farmers and other extension staff.

3.2 Australia

Citrus is one of the largest horticultural industries in Australia, supplying both domestic and export markets. There were 24,000 hectares (ha) of citrus planted in Australia in 2016 with oranges the dominant commodity at 15,800ha and mandarins second with 6,200ha (Citrus Australia tree census, 2016).

Australia exported 189,590 tonnes of oranges at a value of $274 million and 64,100 tonnes of mandarins at a value of $138 million in 2017 (Citrus Australia). The area planted to mandarins expanded by 890 ha from 2014 to 2016 which is a 27% increase.

Worldwide, there is an increasing demand for mandarins due to their perceived quality and convenience (size, ease of peeling, low seed content). In the past fourteen years 34 new mandarin varieties have been introduced to Australia from international breeding and selection programs. There has also been another 10 selections identified in Australia as both natural and induced mutations worthy of evaluation and potential commercialisation.

NSW DPI is responsible for the evaluation of new citrus varieties for the Australian citrus industry. This work is based at the Dareton Primary Industries Institute and has been an on-going program since 1999. Rootstock/scion compatibility, tree and crop management strategies, assessment of fruit quality characteristics and maturity period are all addressed as part of the evaluation process. The Australian citrus industry supports this work through Horticulture Innovation funding with the current project titled ‘Evaluation of new citrus varieties 2017-22.

The ACIAR project allowed the Australian variety evaluation program to be expanded to include more testing and evaluation of the critical management practices needed for successful mandarin production. Furthermore, mandarins require. different, and often a higher level, of tree management than what is required for oranges. But to date, most of the production research undertaken in Australia has focused on oranges, because the production of oranges represents the largest industry sector. Thus practices that enhance early production, improve cropping potential, fruit quality and size of mandarins were examined.

The project also allowed the production of an ‘Australian Mandarin Production Manual’ that provides a comprehensive reference for both existing and new mandarin growers in Australia. This is the first growing manual specifically targeting mandarin production developed for Australian citrus growers.

The project has enabled the improvement of knowledge by Australian scientists about exotic citrus pests and diseases, specifically, HLB and the psyllid vector, powdery mildew and Chinese citrus fruit fly. These pest and disease issues are currently not in Australia and the project staff had the opportunity to work on these problems in Bhutan and assess control methodologies.

4 Objectives

The specific objectives of the project are:

1. **To improve the quality of Bhutanese citrus planting material through germplasm collection, mother tree establishment & improved nursery production practices**: Identify, consolidate and disease screen the best selections of the local mandarin and wild citrus cultivars and establish a national mother tree germplasm repository in an insect proof facility. Identify and source a selection of other high health status, public access citrus cultivars for future evaluation in Bhutan. Improve propagation systems, develop a suitable growing media and implement an appropriate pest and disease management system in production nurseries.
2. **To improve knowledge and management of key citrus pests and diseases**: Continue research work on control options for the key pests and diseases, HLB, citrus powdery mildew, (*Oidium citri*), Chinese citrus fruit fly and investigate other possible vectors and hosts of huanglongbing (HLB). Develop resource materials on citrus pests and diseases for Bhutan.
3. **To improve citrus orchard management practices, nutrition and evaluation of water supply options**: Focus on canopy management, tree nutrition, irrigation requirements and fruit quality improvement. Evaluation of some practical options for permanent water supply and on-farm water storage for orchard farmers. Undertake another citrus grower survey to evaluate improvements in grower knowledge.
4. **To build additional citrus research, development and production capacity of Bhutanese scientists, extension agents and citrus farmers**: Provide specialised training in variety evaluation techniques, mother tree maintenance and testing methods, nursery management and production techniques, irrigation management/design and biometric techniques and trial design. Develop resource and training materials and implement a communication and awareness program for citrus farmers in Bhutan through best practice demonstration sites and citrus focus groups.

5 Methodology

The project was conducted over a 5 year period from 2012 to 2017 with training activities in Bhutan and Australia. The partners in Bhutan were the Department of Agriculture – Horticulture Division, the National Plant Protection Centre (NPPC), the National Soil Services Centre (NSSC), Agricultural Research and Development Centres (ARDCs), the National Postharvest Centre (NPHC), District Extension Services and the National Seed Centre (NSC). The Australian partners were the NSW Department of Primary Industries and Western Sydney University.

The aim of the project was to build on and expand some of the key issues identified in the first project HORT/2010/142 'Improving mandarin production in Bhutan and Australia through implementation of on-farm best management practices'. This project was closely aligned with the national citrus program of the Ministry of Agriculture and Forests and received support from all levels of the Bhutan Department of Agriculture with Australian project staff meeting with the Minister for Agriculture and other senior Bhutan government officials.

The project was administered from the Department of Agriculture offices in the capital, Thimphu with work responsibilities allocated to specific staff at 3 Agricultural Research and Development Centres (ARDC) at Wengkhar (Mongar district), Bhur (Sarpang district) and Mithun sub-centre (Tsirang district), the NPPC, NSSC, NSC and the NPHC.

Activities and training were conducted to address the four objectives of the project:

1. To improve the quality of Bhutanese citrus planting material through germplasm collection, mother tree establishment and improved nursery production practices.

Conservation of the citrus genetic resource in Bhutan is seen as a national priority which required action due to the arrival and spread of huanglongbing (HLB) disease. Securing this material in an insect proof facility and having the capacity to test it for a range of citrus diseases was supported by the project. Citrus selections were collected during district surveys of wild stands of trees and 'mother trees' for commercial propagation established in an insect proof screenhouse at the National Citrus Repository (NCR), Mithun. Additional ACIAR funding was provided to repair and upgrade the Mithun citrus repository during the term of the project.

In country training was also provided by Gary Eyles (Eyles Citrus) a commercial citrus nurseryman with a 100 year family history of citrus nursery management in Australia. Seminars were run for research, extension and nursery staff in November 2014 at Bajo ARDC and at the National Seed Centre at Bhur. Mr Eyles also hosted a Bhutanese officer at his nursery for 2 weeks of intensive training in citrus nursery production as part of a one month stay in Australia.

Kinley Dorji, Senior Research Officer and In-charge at the Citrus Repository completed a 3-week internship program in Australia on citrus disease indexing and diagnostic testing in 2015 with Dr Nerida Donovan at the Elizabeth Macarthur Agricultural Institute (EMAI). The project also sponsored a citrus nursery manager from eastern Bhutan to attend the 2017 International Citrus Nurseryman's Congress in Australia.

A 5 person study tour group including a senior manager from the Department of Agriculture undertook a 2 week study tour in Australia during 2015. The tour included inspections of commercial citrus farms, nurseries and the Australian budwood and seed scheme (Auscitrus) at Dareton, NSW.

A range of public access citrus varieties were introduced to Bhutan during the project. The Bhutanese citrus industry is limited by a short season and dependence on several

mandarin cultivars. Local evaluation and adoption of new, high health status material could expand the season and potentially provide more citrus varietal diversity for both domestic and export markets.

2. To improve knowledge and management of key citrus pests and diseases

The key pests and diseases affecting citrus production in Bhutan are huanglongbing and its Asiatic psyllid vector, Chinese citrus fruit fly and powdery mildew. The project undertook and supported research and extension activities to address these problems.

Dr Andrew Beattie's PhD student Ms Namgay Om completed her PhD in 2017 and returned to Bhutan to her position at the NPPC. Her PhD was based on huanglongbing and its transmission by psyllids. Her new expertise will be a valued resource for the management of HLB in Bhutan. Local trials were established to determine the effects of raising the temperature in young trees with tree guards made from different materials as a means of HLB suppression. The results of this study were not definitive but suggest there could be a relationship between tree guard colour and disease severity.

Project information and images were used by the NPPC to produce a 'Citrus Pests and Diseases Management' booklet, The NPPC also launched a website on Pests of Bhutan and a database with updated information on citrus and other crops.

Chinese citrus fruit fly (*Bactrocera minax*) causes significant crop loss in Bhutan which can be as high as 50% of fruit infested. Entomologist Kiran Mahat, NPPC and his team was able to demonstrate the economic benefits of an area-wide management approach to fly control. This entailed farmer training courses, distribution of baits and traps along with the regular collection of fallen fruit and proper disposal in pits. The momentum for this area of pest control has shifted to his team at the NPPC as he began a John Allwright Fellowship (JAF) PhD program in Australia in fruit fly research during 2015. The initial 'proof of concept' area-wide management studies were conducted in the Tsirang district with the most recent activity in the important citrus growing district of Dagana. Grower survey information often highlights the cultural difficulties of fruit fly management for farmers with Buddhist beliefs unwilling to kill other living creatures, which includes fruit fly maggots and flies.

Powdery mildew control trials were conducted by research staff at Wengkhar and the NPPC in the Tsirang district. The studies looked at the suppression effect of elemental sulphur and horticultural mineral oil (HMO) sprays. Frequency of spray application was also assessed in the Wengkhar trials .Both these sprays could fit into an organic production system which is the vision of government farming policy in Bhutan. Positive results were demonstrated from the research trial established at Wengkhar but achieving these results in the farming community will be difficult because of poor spray equipment, unwillingness to purchase and use chemicals and the large, upright habit of mandarin trees making spray coverage very difficult.

3. To improve citrus orchard management practices, nutrition and evaluation of water supply options

Demonstration citrus orchards were established in 2013 in the major citrus growing districts of Punakha, Tsirang, Sarpang. Chukha, Dagana, Mongar and Lhuentse. The selection and management of the orchards is guided by a 'demo-orchard protocol' produced by the National Citrus Program. These orchards are used for evaluating management practices and their ability to be adopted by the farming community. Management practices implemented on the farms include improvements to nutrition, weed control and basin making, removal of dead wood from trees along with parasitic plants such as Loranthus and pest and disease control strategies. They also act as a resource for both agricultural officer and farmer training through group activities at the orchard. This 'hands-on' method for training has proven most successful for extension of

new information and techniques to local farmers. Literacy levels are often low so 'learning by doing' has proven more successful.

A major area of focus has been on canopy management by pruning of both mature and young trees to improve tree structure and productivity. A project officer (Phuntsho Wangdi - DoA) who has been a key participant in both ACIAR supported projects received one month's training at Dareton Primary Industries Institute in 2009 with an emphasis on canopy management of citrus. He has become the resource and training officer for canopy management in Bhutan and recently assumed the role of nursery manager at the National Citrus Repository, Mithun.

Demonstration farms have also been used to install gravity fed, drip irrigation systems with technical support from Australian project staff. The engineering section of the Ministry of Agriculture and Forests were mandated to establish irrigation systems in horticultural industries in Bhutan to reduce reliance on natural rainfall which is often deficient in the critical developmental stages of flowering and early fruit set in crops such as citrus. A one month training program in Australia was developed for an Agricultural Engineer (Mr Nedrup Tshewang) during 2014 to provide him new skills in drip irrigation design and operation. Post training he has been involved in demonstration irrigation system design and installation, design of a nursery drip irrigation system at the National Citrus Repository and 2 new propagation nurseries being established in eastern and central Bhutan as well as designing the irrigation system for the King's Palace. In country training courses were also provided by Australian project staff and consultants on 'Soil and water management', 'Irrigation engineering and irrigation management' and 'Nursery irrigation management'. To support the development of irrigation for horticultural crops the project also supplied a range of high quality reference books to the Engineering Division on irrigation system design that were purchased and supplied through Irrigation Australia.

The cooperative approach between the Engineering Division who design the drip systems and the extension and research officers who help install, monitor, manage and train the farmers in its use is a successful model which was demonstrated in the term of the project. There was a quick yield and profit response to additional water during the flowering and fruit set periods at the demonstration orchard in Dagana when compared to the 'rain-fed' section of the orchard.

A grower survey was developed by NSW Department of Primary Industries in 2017 to randomly survey farmers in 7 citrus growing dzongkhags (districts), statistically analyse the results and provide a report to the Bhutan Department of Agriculture. The 33 question survey was conducted with 241 farmers from the districts of Punakha, Mongar, Sarpang, Tsirang, Dagana, Chukha and Lhuentse, The survey was conducted by interview between the local district extension officer and the farmer with results complied in Bhutan by Mr Phuntsho Wangdi then sent to Australia for further sorting and analysis. The survey questions were developed to assess the farmer's knowledge and attitudes to chemical use, fruit fly, HLB and powdery mildew control, canopy, soil, fertiliser and nutrition management along with future plans for citrus replanting.

4. To build additional citrus research, development and production capacity of Bhutanese scientists, extension agents and citrus farmers.

The project developed specialised training in Australia for Bhutanese DoA staff in the areas of laboratory diagnostic techniques for disease detection and citrus repository management, irrigation design and management, citrus variety and rootstock management and citrus nursery production techniques and management. The four programs were one month in duration and coordinated through Dareton Primary Industries Institute (Dareton PII), NSW.

Training was also provided in Australia for 2 officers on biometric analysis and trial design through formal course work and practical on site delivery at Dareton PII by senior NSW biometrician, Ms Lorraine Spohr.

A 2 week study tour for senior DoA staff and project officers was conducted in 2015 to review the Australian citrus industry and research facilities. Exposure to a more advanced production system and industry structure was aimed to familiarise key staff with modern horticultural techniques and the diversity of citrus production in Australia.

Training workshops were run in Bhutan by NSW DPI staff and consultants in the areas of 'Citrus nursery management', 'Nursery irrigation management', 'Soil and water management', 'Irrigation system design and management for horticultural crops', 'Managing citrus biosecurity and PCR technologies for plant protection officers' and 'Introduction to basic video production for agricultural officers'. The training programs delivered by Australian project officers and consultants were designed to develop skills in Bhutanese extension, research and engineering staff to enable them to transfer this knowledge to other DoA officers and farmers.

The project supported 3 Bhutanese staff to attend the 12th International Citrus Congress, Valencia, Spain in 2012 and 2 officers to attend the 13th International Citrus Congress in Foz do Iguacu, Brazil in 2016.

Project staff were highly successful in obtaining John Allwright Fellowships for post graduate study in Australia. Four fellowships at PhD level and one for Masters of Science study were awarded with 3 completed with 2 on-going PhD programs as at March 2017. The officers who have completed their studies have returned to Bhutan and re-entered the DoA. An additional 2 officers will be coming to Australia in 2018 for further study. One for a 4 month 'Endeavour Executive Award' scholarship program and the other for PhD study.

6 Achievements against activities and outputs/milestones

Objective 1: To improve the quality of Bhutanese citrus planting material through germplasm collection, mother tree establishment & improved nursery production practices

no.	activity	outputs/ milestones	completion date	comments
1.1 PC	Identify & source best cultivars of local mandarin and wild citrus cultivars A Leader: G. Sanderson PC Leader: Tshering Penjor/ Kinley Dorji	1.1.1 Information on current source material collated 1.1.2 Seed/budwood of best selections collected 1.1.3 Budwood tested for HLB 1.1.4 Trees propagated 1.1.5 Collection established in insect proof repository 1.1.6 Variety evaluation block established	Y1 Y1 Y1-2 Y1-2 Y2-3 Y4-5	76 different accessions (from 38 locations) maintained at ARDC-Wengkhar and introduced to the National Citrus Repository (NCR - Mithun). An additional 30 different accessions collected from backyard and wild stands; being maintained at the repository. HLB testing of repository trees in 2015 found no presence of the HLB pathogen. A total of 115 accessions were propagated and held at the Mithun repository. Public access varieties (PAV) introduced from Australia propagated onto rootstocks at Mithun repository and ARDC Wengkhar and held as mother trees. Variety evaluation block established at ARDC Wengkhar.
1.2 PC	Develop disease testing program for repository trees A Leader: N. Donovan PC Leader: Kinley Dorji	1.2.1 Protocols and a testing program developed 1.2.2 Facilities established and testing begun 1.2.3 Facilities repaired and upgraded	Y1-2 Y3-5 4-5	Protocols for the repository developed in collaboration with NSW DPI and citrus pathologist, Ms Nerida Donovan. Facility upgraded (lab equipment, tools structures) with UNDP support. Indicator plants established for biological indexing, thermal therapy begun, PCR testing in Australia of mother trees, drip irrigation system designed and installed at NCR. Shoot tip grafting begun. Additional funds provided by ACIAR to upgrade covers (damaged by a storm) at the NCR – Mithun with works completed in January 2017.

1.3 PC	Identify & import other public access citrus varieties A Leader: G. Sanderson PC Leader: Jigme Tenzin/ Lakey	1.3.1 Potential varieties identified 1.3.2 High health status varieties imported for future evaluation	Y1-2 Y3-5	Nine public access citrus varieties and 7 citrus rootstock selections supplied from Australia in May 2013, propagated and maintained as mother trees. Sixty high health status buds of Afourer mandarin introduced from Australia for propagation/multiplication and field testing in Tsirang and Mongar districts as a 'focal' village concept. Seven processing orange varieties introduced from Australia in November 2016 to support the development of a citrus juice industry in eastern Bhutan.
1.4 PC	Trial various propagation and potting mixes A Leader: M. Treeby PC Leader: Ganga Singh Rai / S. Chhetri	1.4.1 Suitable mixes & ingredients identified 1.4.2 Local materials sourced for testing 1.4.3 Testing begun on a range of potting mixes	Y1-2 Y1-2 Y2-4	Local materials such as coarse sand, composted sawdust, cow manure and coir selected for testing at the NCR and by the National Soil Services Centre (NSSC). One trial done at the ARDC Bhur with support from the NSSC. Two trials done at the NCR Mithun.
1.5 A	Establish mandarin rootstock/variety planting & undertake evaluation at Dareton, NSW A Leader: G. Sanderson	1.5.1 Trial block prepared and trees planted 1.5.2 Evaluation of early fruit quality characteristics, tree growth, compatibility & initial yield begun	Y1 Y3-5	Replicated rootstock trial planted at Dareton Primary Industries Institute Nov. 2012. Eight rootstocks x 3 trees x 4 reps + buffer trees. Initial data collection on tree growth rate, internal fruit quality, yield and rootstock scion compatibility.

PC = partner country, A = Australia

Objective 2: To improve knowledge and management of key citrus pests and diseases

no.	activity	outputs/ milestones	completion date	comments
2.1 PC	Collect climatic and spray trial data from powdery mildew trial sites. A Leader: M. Treeby PC Leader: Dr. Thinlay/ Loday Phuntsho	2.1.1 Temperature and humidity data from continuous loggers compiled and analysed 2.1.2 Spray trial results analysed 2.1.3 Powdery mildew management program developed	Y1-3 Y1-3 Y4	Data loggers operational at ARDC-Wengkhar (citrus mother block) and Tsirang (farmers' orchard). Powdery mildew management trial using sulphur dust and Horticultural Mineral Oil (HMO) were carried out twice at ARDC-Wengkhar. A positive response with sulphur dust was demonstrated. Trial by the NPPC began with spray schedules undertaken in Tsirang in May 2014 with indeterminate results related to tree size and spray application difficulties.
2.2 PC	Set-up a demonstration of area-wide management of CCFF and trial HMO's on oviposition A Leader: A. Beattie PC Leader: Kiran Mahat/ Phuntsho Loday	2.2.1 HMO trials established and data generated each year 2.2. 2 Area-wide demonstration established, data being collected and analysed 2.2.3 improved CCFF management program developed	Y1-3 Y2-4 Y5	Area-wide Chinese Citrus Fruit Fly (CCFF) demonstration sites set up in Kikorthang in 2013 and Dunglagang (Tsirang district) in 2014. Training was conducted in Tsirang for extension staff and Agricultural Officers by the NPPC to update staff responsible for managing the Area-wide CCFF program. NPPC in collaboration with Dagana district conducted a citrus fruit fly management campaign. The campaign was mainly to disseminate the new techniques and experiences gained from the fruit fly management research activities under the ACIAR project in Tsirang.
2.3 PC	Research on black psyllid as a potential vector of HLB A Leader: A. Beattie PC Leader: N. Om	2.3.1 Experimental program developed 2.3.2 Experimental program begun and data collected 2.3.3 Experimental data analysed 2.3.4 Scientific paper/s developed for publication	Y1 Y2-4 Y2-4 Y5	Studies have indicated that the black citrus psyllid (Diaphorina communis: BCP) primarily feeds and develops on curry leaf (Bergera koenigii), and feeds, but does not develop, on mandarin (Citrus reticulata) and prickly ash/Sichuan pepper (Zanthoxylum spp.) BCP does not transmit 'CLas' from mandarin to mandarin. Ms Namgay Om PhD thesis submitted and accepted 2017.

2.4 PC	Research on curry leaf as a potential host of HLB A Leader: A. Beattie PC Leader: N. Om	2.4.1 Experimental program developed 2.4.2 Experimental program begun and data collected 2.4.3 Experimental data analysed 2.4.4 Scientific paper/s developed for publication	Y1 Y2-4 Y2-4 Y5	No evidence of HLB transmission and nymphs of eggs laid on mandarin seedlings do not mature. No evidence that the black citrus psyllid develops on species of *Murraya* and *Zanthoxylum*. It only appears to develop on curry leaf below 1200 masl. Curry leaf is not a host of '*Candidatus Liberibacter asiaticus'*
2.5 A & PC	Pilot research on polyethylene tree-guards and leaf temperatures for HLB suppression A Leader: A. Beattie	2.5.1 Experimental trials developed 2.5.2 Trials begun and data collected 2.5.3 Experimental data analysed 2.5.4 Scientific paper/s developed for publication	Y1 Y2-4 Y2-4 Y5	Impacts of tree-guards (black metal flyscreen and clear plastic material used in the construction of greenhouses) on leaf temperatures of seedless lemon trees were recorded at Kulnura on the Central Coast of New South Wales from November 2014 to March 2015 using a Campbell Scientific Data Logger. Result: Leaf temperatures were increased by as much as 7°C. An experiment to determine the impact of 'tree-guards' made from a range of materials was established at 800m ASL at Phunsumgang (formerly Gharigaon) in Tsirang in late June 2014 in order to determine the impact of the materials on leaf temperatures and huanglongbing infected, field-planted, mandarin seedlings obtained from a nearby nursery 1000 masl. Experiment completed Oct 2015. Result: No positive result in tree guard effects on HLB suppression.
2.6 PC	Produce advisory materials on pests & diseases PC Leader: Jigme Tenzin/ Lakey	2.6.1 Citrus pest and disease guide for Bhutan in production 2.6.2 Bhutan guide released	Y1-3 Y4	Website and database with updated pest information (Pests of Bhutan) compiled and launched by NPPC with technical assistance of an Australian Volunteer in 2016. Publication on 'Citrus Pests and Diseases Management' developed by the NPPC and incorporating information generated from the ACIAR project pest management research released in 2017.

PC = partner country, A = Australia

Objective 3: To improve citrus orchard management practices, nutrition and evaluation of water supply options

no.	activity	outputs/ milestones	completion date	comments
3.1 PC	Establish demonstration orchards in key locations A Leader G. Sanderson: PC Leader: Jigme Tenzin/ Lakey	3.1.1 New demonstration sites identified and local managers appointed 3.1.2 New demonstration sites established and managed	Y1 Y1-2	Seven demonstration orchards established in 2013 and on-going for the life of the project. Orchard programs directed by the demo-orchard guidelines produced by the National Citrus Program, and are being implemented in all the demo-orchards in Punakha, Tsirang, Sarpang, Chukha, Dagana, Mongar and Lhuentse.
3.2 PC	Undertake key management practices on demo orchards A Leader: M. Treeby & G. Sanderson PC Leader: Jigme Tenzin/ Lakey	3.2.1 Calendar of activities for demo orchards formalised and document produced 3.2.2 Management practices: pruning; weeding; pest & disease control , fertiliser, water & gibberellic acid GA application implemented in accordance to site activity calendar 3.2.3 Canopy management recommendations for young and mature citrus trees developed and extension material produced	Y1 Y2-5 Y4	Key orchard management practices as outlined in the citrus production guidelines initiated by respective ARDCs. Basic farm inputs provided through the project. Gibberellic Acid (GA) trials for improving mandarin skin condition conducted at the ARDC Wengkhar and National Post-harvest Centre (NPHC) A 2 day field training program on citrus orchard management practices conducted for extension officers at the Punakha demonstration orchard on the 29-30 March 2016. Topics include: citrus phenology, canopy management and pruning, nutrition, irrigation, pest and disease, yield and fruit quality recording. Orchard management highlighting canopy management was conducted on an area-wide approach in Drujegang geog (Dagana) involving around 320 households in 2015/16 with on-going support from DoA officers from Tsirang and Punakha. A 3 day (53 participants) and 1 day (40 participants) field training program on citrus orchard management practices conducted for farmers and extension officers in the Sarpang district from the 11-15th Jan. 2017. Topics included: calendar of orchard activities, canopy management and pruning, nutrition, pest and disease.

3.3 PC	Monitor nutritional status of mandarin orchards A Leader: M. Treeby & G. Sanderson PC Leader: S. Chhetri	3.3.1 Monitoring program developed and sites for sampling selected 3.3.2 Soil samples collected at selected sites and analysed 3.3.3 Leaf analysis conducted 3.3.4 Fertiliser records collected annually and collated 3.3.5 Recommended fertiliser programs developed and refined with NSSC	Y1 Y3 & 5 Y3 & 5 Y2-5 Y5	Soil and leaf analyses conducted annually (2013-2016) on demo-orchards in Dagana, Sarpang and Chukha districts. Fertiliser records collected from demo-orchards and from citrus growers. Farmers in Tsirang, Dagana & Sarpang have been trained by staff from the NSSC on integrated nutrient management for citrus. Extension officers from Punakha trained on nutrient management in citrus in March 2016. Fertiliser recommendations developed by the NSSC for citrus finalised and available.
3.4 PC	Design & establish a suitable water collection and application system for pilot demonstration A Leader: J. Giddings PC Leader: Nedrup Tshewang	3.4.1 Demonstration site identified and pilot system designed 3.4.2 Irrigation system equipment and weather monitoring equipment purchased 3.4.3 Equipment installed and functioning at test site 3.4.4 Irrigation system and operational feasibility evaluated annually	Y1 Y1 Y1-2 Y2-5	Drip irrigation system installed and operational at the demonstration site at Thangna, Drujeygang, (Dagana) in 2013. System design and infrastructure support provided by NSW Dept. of Primary Industries. Data collection on irrigated soil moisture status, crop yield and quality at key demonstration sites at Punakha, Thangna and Wengkhar. Rapid expansion of gravity fed micro-irrigation demo farms in Bhutan (total of 20) in 2016 driven by the Engineering section of the Ministry of Agriculture and Forests (MoAF) with the ACIAR demo orchard at Thangna acting as an early ‘catalyst’ and model for adoption.

3.5 PC	Determine citrus water requirements for key growing regions A. Leader: J. Giddings PC Leader: Kinley Dorji	3.5.1 Tensiometers installed at selected demonstration sites 3.5.2 Regular soil moisture data collected from tensiometers 3.5.3 Data analysed and reported for different citrus production regions	Y1 Y2-4 Y4-5	Tensiometers installed and in use at Thangna (Dagana), Damchoe (Kabjisa) and Pemathang (Tsirang) demo orchards and at ARDC-Wengkhar and ARDC-Bhur. Irrigation scheduling, crop water requirements and timing evaluated at Thangna (Dagana) demo orchard. Irrigation training provided to 21 extension personnel and 6 farmers from the key citrus production region of Dagana from the 24-25th June 2017. ARDC-Wengkhar continued to upgrade their mobile phone activated irrigation system (field and nursery) to an internet and web-based control system. This enabled multi-irrigation scheduling, control of irrigation duration and weather-based irrigation scheduling besides rendering it more user-friendly. Australian electronic equipment was supplied to aid the upgrades.
3.6 PC	Undertake mandarin grower survey A Leader: G. Sanderson PC Leader: Jigme Tenzin/ Phuntsho Wangdi	3.6.1 Survey designed and conducted 3.6.2 Results collated, analysed, compared to baseline data and reported	Y4-5 Y5	Designed by NSW DPI biometrics section in consultation with the Bhutan project leader and provided to Bhutan for distribution to extension officers in 2017. The survey sampled 241 households in the 7 ‘project active’ districts of Bhutan. Statistical analysis of results will be finalised in March 2018 with a report provided to the Bhutan DoA and ACIAR.

3.7 PC & A	Undertake trials on growth regulators for improving mandarin fruit quality and regulate crop load A Leader: G. Sanderson PC Leader: Loday Phuntsho/ Karma Dorji	3.7.1 Trial experiments planned 3.7.2 Trials conducted on mandarin varieties 3.7.3 Data analysed 3.7.4 Report and extension material produced	Y1 Y2-4 Y2-4 Y5	Second year results (2016) from Wengkhar trials confirmed that Gibberellic Acid (GA) treatment slowed colour development in mandarin fruit but had no significant effect on increasing rind thickness. Trial results from the NPHC showed no significant difference in the delay of fruit colour development with GA application. **Australia -** GA applied at 30ppm at 50%-80% flowering in 2015 and again in 2016 as a split application of 15ppm and another 15ppm 2 weeks later, in combination with limb cincturing, improved fruit set on Orri mandarin only in 2015. The 2016 fruit set was affected by excessive vegetative growth at the expense of crop load. Stop Drop™ (2,4-D) was applied at petal fall, October 2015 to M7 navel and at a similar timing to Daisy mandarin from 2014-16 at 10ppm to assess its effect on closing the 'navel end' of fruit and reducing fruit splitting. Result: Positive effect on reducing fruit splitting. GA was applied in early January 2016 to improve rind condition at harvest of new varieties under evaluation (Orri and Gold Nugget mandarins)

PC = partner country, A = Australia

Objective 4: To build additional citrus research, development and production capacity of Bhutanese scientists, extension agents and citrus farmers

no.	activity	outputs/ milestones	completion date	comments
4.1 A & PC	Specialised training in Australia A Leader: G. Sanderson PC Leader: JigmeTenzin/ Lakey	4.1.1 Training programs and timetable developed and Bhutan staff identified 4.1.2 Citrus variety and rootstock evaluation training program developed and delivered 4.1.3 Citrus nursery production training developed and delivered 4.1.4 Diagnostic, laboratory and citrus repository management training developed and delivered 4.1.5 Irrigation design and management training developed and delivered	Y1 Y2-5	Potential staff for extended training (one month) in Australia short listed. Five DoA officer 2 week study tour to Australia in June 2015 to view the Australian citrus industry, nurseries, packing houses, commercial farms and research facilities. Completed July 2015 Completed Nov/Dec 2016 Completed May 2015 Completed June 2014
4.2 PC	Irrigation & soil moisture monitoring training A Leader: J. Giddings PC Leader: Jigme Tenzin/ Lakey	4.2.1 Soil moisture monitoring and irrigation training workshop delivered in Bhutan	Y2	*Irrigation related training by Australian professional officers.* Four-day training workshop for agricultural engineers on '*Irrigation Design & Management for Horticultural Crops*' conducted in Thimphu, May 2014. Workshop presented by Rural Solutions, South Australia consultant and NSW DPI project officer. Two-day training course on '*Irrigation and Soil Management*' at the ARDC-Bajo in May 2014 was attended by 15 research and extension officers. Two-day training course on '*Irrigation and Soil Management*' at the ARDC-Wengkhar in April 2016. Two-day '*Nursery Water Management*' course at Thimphu in April 2016.

4.3 A	Biometrical training A Leader: L. Spohr PC Leader: Jigme Tenzin	4.3.1 Specialised biometrical training for Bhutan DoA extension & research staff developed 4.3.2 Biometric training course delivered in Bhutan	Y1-2 Y3-5	Biometric and trial design training conducted in Australia for two Department of Agriculture (DoA) officers in October 2015.
4.4 PC & A	International conferences A Leader: G. Sanderson PC Leader: Jigme Tenzin	4.4.1 Attend International Citrus Congress in 2012 and 2016	Y1 Y4-5	Three DoA project officers attended the 12th International Society of Citriculture (ISC) Congress, Spain, 2012. One Australian project officer attended. Two DoA officers attended the 13th ISC Congress, Brazil in 2016. Two Australian project officers attended. DoA officer attended the International Society of Citrus Nurseryman's (ISCN) Congress in Australia, 17th – 27th July 2017.
4.5 PC	National training & awareness program for Bhutanese citrus farmers A Leader: S. Falivene PC Leader: Jigme Tenzin/ Lakey	4.5.1 Training modules for key citrus production practices for Bhutanese farmers identified and under development 4.5.2 Deliver training modules 4.5.3 Video awareness program for key citrus management activities under development 4.5.4 Scripts and video footage of key management activities developed 4.5.5 'Horticultural hints' training videos developed and broadcast on national television/social media.	Y1-3 Y3-5 Y1-2 Y2-3 Y4-5	A 3-day video training workshop "*Introduction to Basic Video Production for Agricultural Officers" was* conducted at ARDC-Bajo in February 2014 for 13 MoAF officers. 7-minute video program produced. The video training and equipment provided by Australian project staff has assisted in the local production of short videos. A summary video of the April 2016 'Irrigation training courses' was produced and shown to senior MoAF staff. Farmer focussed training on canopy management conducted by Bhutan project officers in Dagana , Sarpang, Pemagatshel and Tsirang districts. Training programs including canopy, nutrition, irrigation and fruit fly management delivered to 1483 farmers to 2016.

PC = partner country, A = Australia

7 Key results and discussion

1. To improve the quality of Bhutanese citrus planting material through germplasm collection, mother tree establishment & improved nursery production practices

Establishment and maintenance of the National Citrus Repository at the Agricultural Research and Development sub-centre, Mithun.

A National Citrus Repository (NCR) was established in 2011 to hold and maintain disease free mother trees of both local citrus selections and varieties introduced from countries such as Australia. ACIAR projects have provided technical support and training to develop local staff capacity to manage an 'insect proof' facility. An operating procedures protocol was developed in 2014 with assistance from project officer Dr Nerida Donovan (citrus pathologist) along with an inventory of plant and equipment to run a citrus pathology laboratory.

The NCR is a key component in the rehabilitation of the Bhutan citrus industry. Disease free citrus trees need to be maintained for the supply of high health status budwood for propagation. The facility holds 115 accessions of both local and introduced citrus selections with initial testing of 47 mother trees in Australia finding no huanglongbing (HLB) affected trees in 2015. Mother tree budwood was brought to Australia under strict protocols for testing at the Elizabeth Macarthur Agricultural Institute by Mr Kinley Dorji (senior research officer, manager of the NCR Mithun) as part of his pathology and nursery management training program.

Storm damage and deterioration of the insect screen mesh in 2015 required the facility to undergo major repair work. ACIAR provided additional funds to put a new cover on the insect proof screenhouse and repair the roof on the polycarbonate propagation house.

An automated drip irrigation pot watering system was designed and installed in 2015 by an agricultural engineer (Mr Nedrup Tshewang) who received training in Australia during 2014.

Long term project officer Mr Phuntsho Wangdi who has been a key contributor to the ACIAR citrus projects since 2007 was appointed as on-site manager at the NCR Mithun in 2017. This is a positive initiative as Mr Wangdi has a strong work ethic and has received one months' horticultural training at Dareton Primary Industries Institute in 2009 and led a 5 person citrus study tour to Australia in 2015. Mr Wangdi is also an experienced trainer in canopy management techniques and is an important resource person for the DoA in Bhutan.

Collection and maintenance of local citrus genetic resources

Active and on-going collection programs have been conducted in Bhutan over the life of this project. Mr Kinley Dorji has collected mandarin selections and 'wild' types from both orchards and backyards in districts such as Samste, Sarpang, Punakha, Tsirang, Wangdue, Zhemgang and Mongar. These have been propagated and held at the NCR Mithun. The aim is to preserve and centrally locate commercially important mandarin selections as well as native citrus types. The threat of varietal loss with the spread of HLB requires a secure, disease free repository that will be able to supply high health status propagation material to citrus propagation nurseries. Commercially important mandarin selections include: Dorokha local (*Citrus reticulata* Blanco), produced from Dorokha in the Samtse district and is preferred both by local consumers and export vendors. Similarly, Tsirang local (*Citrus reticulata* Blanco), from the Tsirang district is mostly preferred by local consumers in the west and central regions. In the east, Kengkhar Tshalu is known for its flavour over the other mandarin type.

Mr Tshering Penjor, senior research officer at the ARDC Wengkhar has collected a wide range of indigenous citrus species from eastern Bhutan and maintains them in a nursery facility and on-station field site. These include native citron, pummelo, lime, rough lemon and *Citrus ichangensis* selections. Some hybridising work has been done with high altitude *C. ichangensis* to test the progeny as potential rootstocks with enhanced cold tolerance. Mr Penjor has also recently completed a PhD in Japan on the genetic diversity of Bhutanese citrus.

Introduction of public access citrus varieties and rootstocks from Australia

The Bhutanese citrus season is limited to an approximate 4 month period, determined by location, elevation and based on one mandarin type. There have been 3 introductions of public access citrus varieties to Bhutan for propagation, evaluation and establishment of mother trees. The aim is to provide a wider range of proven citrus varieties for potential commercialisation and expansion of the local citrus industry.

Table 1. Status of public access budwood and rootstock varieties at ARDC Wengkhar

No.	Common name	Scientific name	Variety	Type	No. of potted plants	No. of plants in the field
1	Navel Orange	*C. sinensis*	Cara Cara	Budwood	3	2
2	Navel Orange	*C. sinensis*	Ryan	Budwood	1	1
3	Common orange	*C. sinensis*	McMahon Valencia	Budwood	1	1
4	Common orange	*C. sinensis*	Salustiana	Budwood	1	1
5	Pigmented orange	*C. sinensis*	Tarocco Ippolito	Budwood	2	2
6	Common mandarin	*C. reticulata*	Amigo	Budwood	1	1
7	Clementine mandarin	*C. reticulata*	Caffin	Budwood	1	1
8	Pigmented grapefruit	*C. paradisi*	Cant Star Ruby	Budwood	1	1
9	Citron	*C. medica*	Buddha's Hand	Budwood	1	1
10	Swingle rootstock	*C. paradisi x P. trifoliata*	Swingle Citrumelo	Rootstock	2	2
11	Flying dragon	*P. trifoliata*	Flying Dragon	Rootstock	1	-
12	Common mandarin	*C. reticulata*	Afourer	Budwood	14	2 (top-worked)
13	Common orange	*C. sinensis*	Pera Limeira	Budwood	4	-
14	Sweet orange	*C. sinensis*	Berri Valencia	Budwood	3	-
15	Common orange	*C. sinensis*	Parson Brown	Budwood	3	-
16	Common orange	*C. sinensis*	Natal	Budwood	4	-
17	Common orange	*C. sinensis*	Hamlin	Budwood	4	-
18	Sweet orange	*C. sinensis*	Keenan Valencia	Budwood	3	-
19	Sweet orange	*C. sinensis*	Benyenda Valencia	Budwood	3	-

The budwood introduced from Australia was sourced from Auscitrus as high health status except Amigo mandarin which was supplied as best available material. Budwood was distributed to the NCR Mithun, ARDC Wengkhar and ARDC Bhur for propagation with Wengkhar the main field site for evaluation. Varieties 1-9 (Table 1) were introduced to Bhutan in 2013 with the first fruit produced on several varieties in 2016. The second introduction was Afourer mandarin and occurred in April 2016. This variety has the potential to be seedless if isolated from other citrus and will be tested at a 'focal village' as the sole citrus variety grown. Afourer mandarin has become one of the most popular new mandarin varieties in the world in recent years. The third introduction was varieties 13-19 in October 2016. These selections are processing oranges and were introduced to support the future development of a processing citrus juice industry in eastern Bhutan.

Figure 1. New variety field evaluation trees at ARDC Wengkhar covered in mesh to protect fruit from Chinese Citrus Fruit Fly.

Rootstock seed introductions

Rootstock seed was introduced for evaluation in 2013 and included scarlet mandarin x *P. trifoliata* hybrids 3812, 3822, 3834 and 3835 bred by NSW Department of Primary Industries in 1960 and currently under evaluation as potential rootstocks for mandarins at Dareton Primary Industries Institute. Large volumes (kgs) of rootstock seed was also sent to Bhutan via Auscitrus or carried as quarantine inspected luggage on scheduled visits. The predominant types have been *P. trifoliata*, citrange and swingle. This was to provide seed for commercial scale propagation of rootstocks by the National Seed Centre and ARDC's for grafting to mandarins for supply to farmers. There is a need to reduce the reliance on mandarin trees grown from seed as it can take up to 7 years for a tree to produce fruit. During this extended timeframe there is a strong probability of infection with HLB and tree decline before an economic return is achieved. Grafted trees can produce their first crop 4 years from field planting.

Table 2. Citrus rootstock introductions to Bhutan 2013 for evaluation and mother tree establishment.

Description			% seed germination as at April 2014		
Common	Scientific	Variety	Mithun	Wengkhar	Bhur
Hybrid	*C.reticutata x P.trifoliata*	3812	15	90	65
Hybrid	*C.reticutata x P.trifoliata*	3822	10	*	12
Hybrid	*C.reticutata x P.trifoliata*	3834	11	*	9
Hybrid	*C.reticutata x P.trifoliata*	3835	8	*	27
Swingle	*C. paridisi x P. trifoliata*	Swingle citrumelo	29	90	51
Flying Dragon	*P.trifoliata*	Flying Dragon	Not sown	90	24
West Indian Lime	*C.aurantifolia*	West Indian Lime	Not sown	*	12

Development of disease testing capacity for NCR trees

The laboratory facility at the NCR Mithun received funding via the UNDP to upgrade its equipment and testing capacity. A quarantine and diagnostic propagation house has been established at the NCR. Biological indicator plants grown, a protocol for thermo therapy developed, micro grafting (shoot-tip) successfully done at Wengkhar and trialled at Mithun.

Mr Kinley Dorji (senior research officer, manager of the NCR Mithun) undertook 3 weeks training in citrus pathology testing in 2015 at the Elizabeth Macarthur Agricultural Institute under the supervision of Dr Nerida Donovan, Citrus Pathologist. Dr Donovan also helped to develop an operating protocol for the Mithun facility and resources inventory required for a plant pathology laboratory. Plant pathology officers from the NPPC were delivered a seminar and training on PCR protocols and methods in October 2016 at Thimphu.

Dr Namgay Om successfully completed her PhD studies on huanglongbing (HLB) and disease transmission by psyllids in 2017. She has now resumed her senior role in the NPPC and is directing the efforts to manage HLB through the production of non-infected seedling trees.

Trial a range of potting media

A trial protocol was developed by Dr Michael Treeby, NSW DPI to evaluate combinations of materials suitable for citrus potting mixes that are available in Bhutan. These included coarse sand, sawdust, aged cow manure and coir coconut fibre, available from India. A composting procedure for sawdust was also provided which has been used in Australia to make it suitable as a potting mix ingredient.

The potting mix trial was established at the Dareton Primary Industries Institute nursery on the 4th March 2014 to test the likely plant responses to the 7 potting mix combinations. The Bhutan trials were begun in May 2014 at the ARDC Bhur and the ARDC sub centre Mithun (Tsirang). The trial in Bhur used citrus seedlings while the one at Mithun was established using Trifoliata rootstock seed.

A standard procedure for determining the air filled porosity (AFP) of a potting mix was adapted from Handreck, K and Black, N. (2010) ‘Growing media for ornamental plants and turf’ with a pictorial guide compiled for use in Bhutan. Air filled porosity is a critical factor in the quality determination of a potting mix. A device to measure AFP was constructed and two sent to Bhutan and training in its use and application was provided to nursery staff during the Australian staff visit in May 2014.

Results demonstrated that the combination of 66% coarse sand and 34% composted sawdust (2:1) was the best combination of the 7 under test for incremental plant growth at the ARDC Bhur. Trials at the NCR Mithun saw 50% coarse sand and 50% composted sawdust (1:1) give the best growth rate. Seedling growth at both trial sites was superior to the standard nursery mix of forest compost/soil and cow manure which is typically used for seedling propagation. The results have stimulated a greater use of coarse sand as a way of increasing the Air Filled Porosity in citrus propagation media.

Mandarin rootstock trial at Dareton Primary Industries Institute (Dareton PII)

A mandarin rootstock trial was established at Dareton PII on the 1/11/2012. The rootstocks consist of 5 hybrids of Scarlett mandarin x trifoliata orange developed from a NSW DPI citrus rootstock breeding program in the early 1960’s at Gosford Horticultural Research Station. Four of the five selections (3812, 3822, 3834 and 3835) were identified from earlier trials as having potential as mandarin rootstocks and need further evaluation. The fifth hybrid (Cox) has recently become a commercial rootstock for Eureka lemon in Australia. Other rootstocks in the trial include Mantouhong mandarin from China and 2 commercial rootstocks for comparison (C35 citrange and Carrizo citrange).

Selections 3812, 3822, 3834, 3835 and Mantouhong mandarin were established as rooted cuttings under a misting system with bottom heat while Cox, C35 citrange and Carrizo citrange rootstocks were propagated from seed.

The scion variety is a new, high quality, low seeded PBR mandarin variety called Tang-Gold that is well adapted to the Sunraysia climate and is currently being commercialised in Australia.

The trial is biometrically designed and replicated with drip irrigation and a standard young tree fertigation program. Fruit quality evaluation and yield data collection began in 2015. Analysis of the first 4 years of data will occur in October 2018.

Rootstock seed of 3812, 3822, 3834 and 3835 were also taken to Bhutan in May 2013 for propagation and testing as potential future citrus rootstocks for Bhutan.

National evaluation of new citrus varieties in Australia

The ACIAR project added value to Horticulture Innovation project CT12026: 'Evaluation on new citrus varieties 2013-17' running concurrently at Dareton PII. The evaluation site was used as a training resource for Bhutanese staff and a selection of public access varieties that have been evaluated through the long-term programs at Dareton introduced to Bhutan for evaluation.

2. To improve knowledge and management of key citrus pests and diseases

Chinese Citrus Fruit Fly (CCCF)

In 2012 a fruit fly incidence survey was conducted in 3 citrus growing districts of Tsirang, Sarpang and Dagana to determine the level of infestation and fruit drop associated with CCCF. As a result of the survey a management program was developed by the National Plant Protection Centre (NPPC) to research the problem at an area and village scale. Strategies involved the use of protein baits, trapping and the collection and disposal of fallen fruit. An area-wide management approach with associated farmer training was applied during 2013 and 2014 in the Tsirang geogs (sub districts) of Kirorthang and Dunglagang. The NPPC in collaboration with the Department of Agriculture and the local district sector at Tsirang trained 270 farmers to implement the area-wide management strategy. Knapsack sprayers, insecticide and protein bait were supplied to the participants as well as chemical use, fruit fly biology, timing of activities training and data sheets to record dropped fruit numbers. In the first year 18% of sampled fruit had fruit fly damage compared to 59% of fruit from non-treated areas and in the second year a similar result with 19% of sampled fruit affected by CCCF and 64% of fruit from non-treated areas. The coordinated area-wide management approach resulted in higher yields for those participating farmers and an increase in monetary returns.

Community based fruit fly management has also been promoted and applied in the eastern districts of Mongar and Lhuentse with support from the NPPC during 2013 as an initiative of the ARDC Wengkhar. Protein-bait spraying, CCCF trapping and formal training were provided to 52 citrus farmers along with fruit collection strategies to reduce local populations of fruit fly. A similar campaign was also implemented during 2016 in the Dagana district of southern Bhutan in build on CCFF program run in 2012 and 2013.

The 2012-13 area-wide management program run in Drujeygang (Dagana), demonstrated both production and cash income improvements as a result of the intensive CCFF management approach supported by the NPPC and project

Figure 2. Difference in production before (2012) and after (2013) intervention (Drujeygang, Dagana)

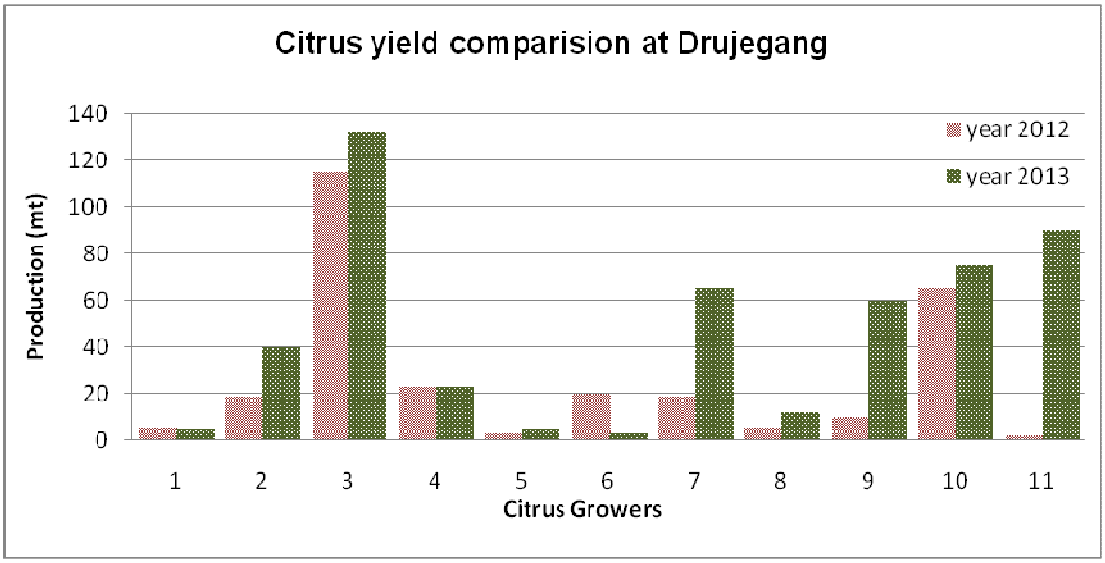
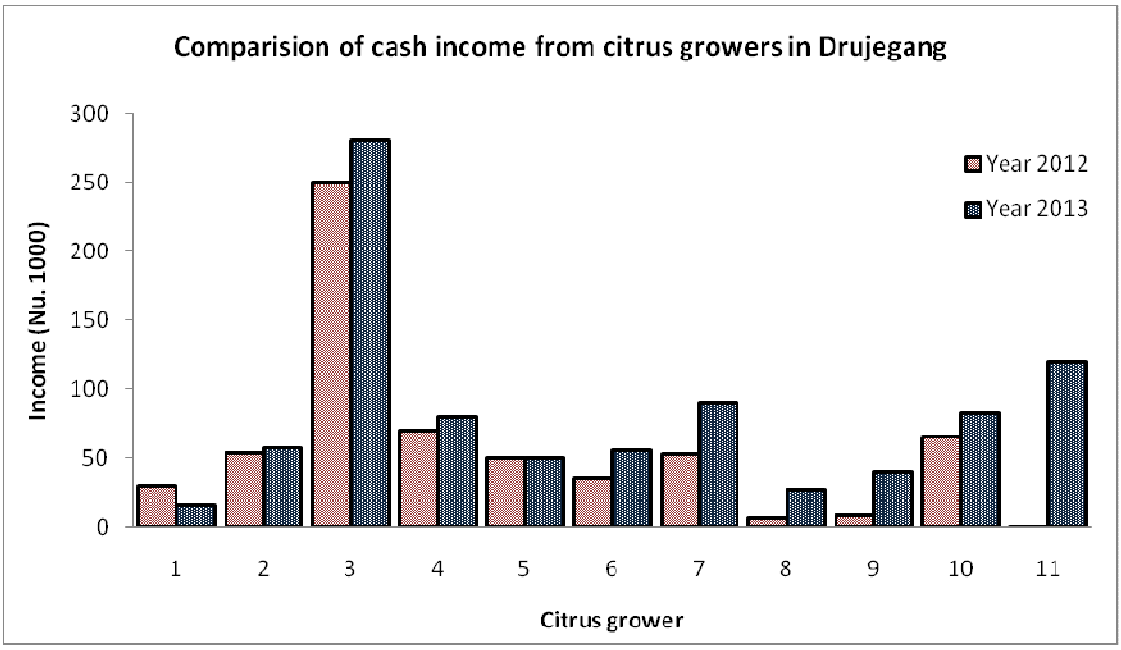


Figure 3. Changes in the income of growers, 2012 to 2013 (Drujeygang, Dagana)



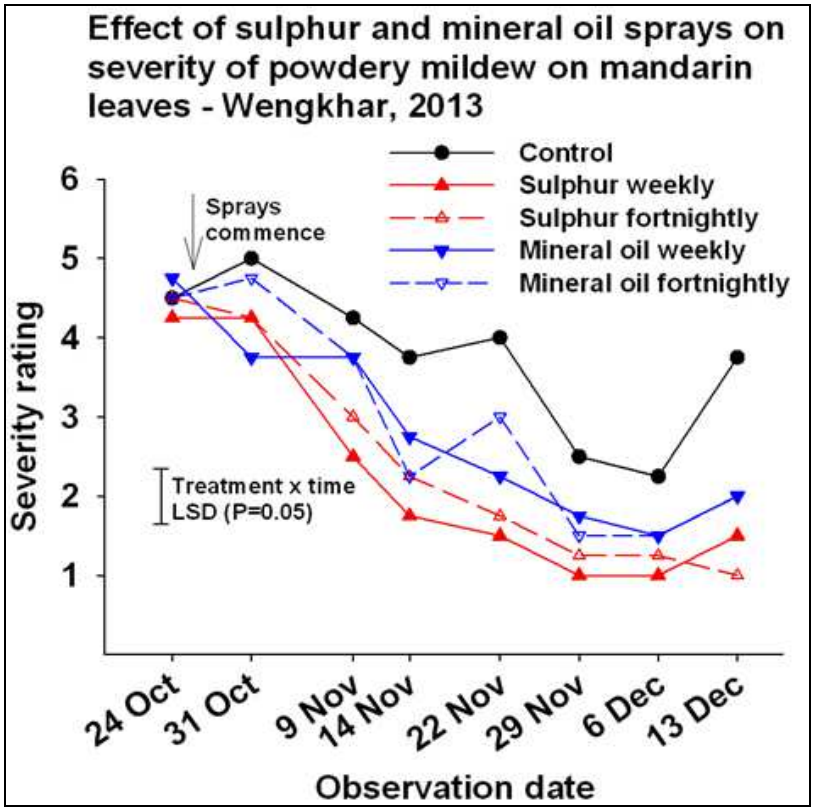
Bhutan Department of Agriculture entomologist Kiran Mahat was the driver of the area-wide management approach to CCCF control and testing of protein bait formulations. He gained a John Allwright Fellowship and began PhD studies on fruit fly control at Queensland University of Technology in 2015.

Powdery Mildew

Powdery mildew suppression trials were conducted by the NPPC in Tsirang and research staff at the ARDC Wengkhar. The trials compared the frequency of application of two spray materials - namely, wettable sulphur and a miscible mineral oil on tree health as indicated by the proportion of the leaf surface infected, and the presence of twig dieback and defoliation. The trial was run over two years at ARDC Wengkhar and showed that the extent of the disease diminished with time, but if the trees had been sprayed the extent of the decrease over time was greater, and that sulphur was more effective than mineral oil. Weekly application of either material was generally no more effective than fortnightly applications. The trials at ARDC Wengkhar were conducted on

smaller, managed trees on the research station whereas the NPPC trials were on larger trees at a farmer property. Results were indeterminate for the NPPC trials in 2014 possibly due to the difficulty in achieving adequate spray coverage on large, upright trees.

Figure 4.



Studies on huanglongbing (HLB) and the citrus psyllids

The overarching aims of the studies in Bhutan were to determine the role of *Diaphorina communis* (black psyllid) as a vector for '*Candidatus* Liberibacter asiaticus', to provide information on the influence of various environmental factors on the disease, its vectors and host plants. Ms Namgay Om commenced her PhD studies at Western Sydney University on the black psyllid and HLB transmission in August 2012, after being awarded a John Allwright Fellowship. Namgay spent 6 months of every year in Australia and 6 months in Bhutan undertaking the field work under the supervision of Dr Andrew Beattie. She was awarded her PhD in 2017 and returned to a senior role in the NPPC, Bhutan.

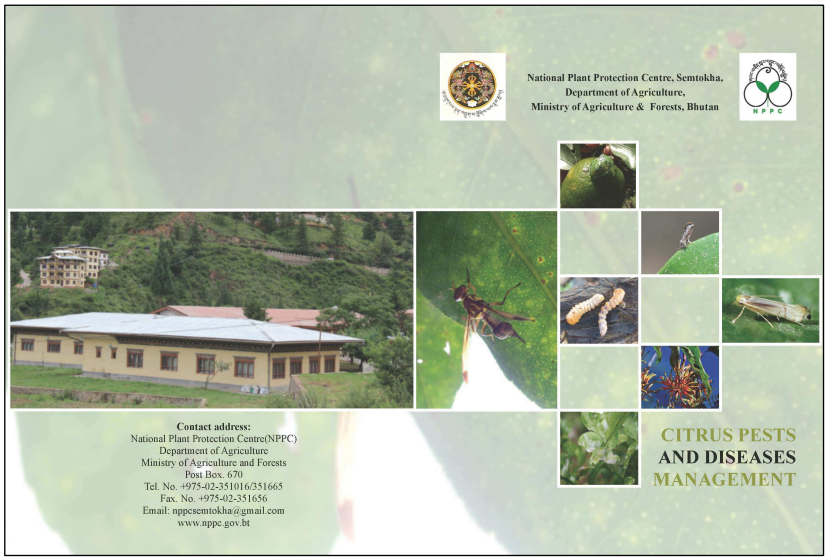
Highlights of the research program include:

- *Diaphorina communis* adults can acquire the HLB pathogen,'*Candidatus Liberibacter asiaticus'* ('*C*Las') but at a low rate.
- *Diaphorina communis* feeds and develops exclusively on curry leaf when given a choice. However, a low to negligible rate of development of *Diaphorina communis* observed on mandarin under no-choice conditions.
- There is no evidence that curry leaf can harbour '*C*Las'.
- No evidence of transmission of '*C*Las' by *Diaphorina communis* from infected mandarin to mandarin or curry leaf could be established. *Diaphorina citri* is more commonly found below 1200 m while *Cacopsylla heterogena* is found quite abundantly at higher altitudes. '*Candidatus Liberibacter asiaticus'* is more prevalent at elevations up to 1100m. At elevations above 1200 m, '*C*Las' may have been introduced in planting materials but remained localised due to

absence of *Diaphorina citri* at these altitudes. In the absence of a vector, it is possible to grow mandarins and other *Citrus* species and hybrids above 1200 m using pathogen-free planting material.

- Three species of green psyllids occur in Bhutan, one on citrus and two on *Zanthoxylum* sp. The green psyllid occurring on mandarin, wild citrus, lemons, limes and oranges in Bhutan belong to one species, *Cacopsylla heterogena*.
- The two psyllids collected from the *Zanthoxylum* sp. are confirmed as *Cornopsylla rotundiconis*, and the other is an undescribed species of *Cacopsylla*.
- *Cacopsylla heterogena* can acquire '*C*Las' under field conditions.
- There is no evidence of '*C*Las' in *Cornopsylla rotundiconis* and *Cacopsylla* sp., the green psyllid species recorded on *Zanthoxylum* sp.

Figure 5. Citrus Pest Management booklet



'Citrus Pests and Diseases Management' was published in 2017 by the National Plant Protection Centre (NPPC) incorporating the latest information generated from the ACIAR project on managing citrus pests and diseases in Bhutan.

Pests of Bhutan Website and Database

The NPPC launched the website on 'Pests of Bhutan' and a Database with all updated information on citrus and other crops. Current citrus pest information was provided from ACIAR project activities in Bhutan.

3. To improve citrus orchard management practices, nutrition and evaluation of water supply options

Demonstration orchards

Seven demonstration orchards were established in collaboration with the Agricultural Research and Development Centres (Bajo, Bhur, Wengkhar, Mithun and Yusipang) and were active for the term of the project. These pilot orchards are situated across seven citrus growing districts in Bhutan and included Punakha, Tsirang, Sarpang, Lhuentse, Mongar, Chukha and Dagana. The orchards provide a training resource for capacity building programs developed for farmers and extension personnel. The training programs concentrate on practices such as canopy management, nutrition, and pest and disease control.

Canopy management

A canopy management campaign was conducted during the project to educate farmers on the benefits of tree management. A core group of extension officers and senior staff have received training in canopy management to enhance practice change in citrus farm communities. Mr Phuntsho Wangdi spent one month in Australia during 2011 and received practical training in orchard management with an emphasis on pruning and canopy manipulation. He has since imparted his skills to other extension staff and farmers in a range of workshops and training courses in Bhutan.

In the Tsirang district canopy management was undertaken in all 12 geogs covering around 80% of citrus orchards and involving 469 farmers. Nearly all farmers wanted to implement canopy management - the main constraint was the amount of time local extension agents had to demonstrate the practices. A similar initiative in the Dagana district saw 320 household receive canopy management training with funding support provided by ACIAR. In Sarpang and Pemagatshel workshops on orchard management trained 86 farmers and 6 extension staff with hands-on activities that resulted in the complete pruning on five citrus orchards.

Anecdotal reports of improvements in the number of new shoot which can develop fruit along with improved fruit size have been received from farmers adopting pruning practices. An economic analysis of the monetary implications of improved canopy management needs to be conducted.

Irrigation and water management

A lack of irrigation is a deficiency in Bhutanese farming, particularly in horticultural production. Citrus orchards in the country are almost entirely rain-fed. The Ministry of Agriculture and Forests has focussed major emphasis on the development and set-up of irrigation infrastructure as part of its 11th five year plan.

A gravity-fed, drip irrigation system was installed in 2013 at the demonstration site at Thangna, Drujeygang geog (Dagana). The site was selected in consultation with the Drujeygang extension service and the Engineering Division (Department of Agriculture) as part of the project's irrigation component. Pressure compensated drippers from Australia, joiners and hand drills were provided by the project while other components of the drip system were funded by the Engineering Division (Department of Agriculture).

A total of 145 trees in the orchard were fitted with a drip system with 4 emitters (4l/h) covering a wetting area of 120 cm^2 a tree. The installation followed a design developed by the Engineering Division and NSW DPI. Tensiometers were installed and weather data collected from a nearby Class C weather station. The grower and the extension personnel were taught to operate the system and to carry out basic maintenance such as flush-out of silt from the mains and the laterals. The remaining 117 trees were maintained as a rain-fed control. Other orchard management practices such as nutrition timing were provided to the farmers with records maintained by the local extension officer. The rapid expansion of gravity-fed micro-irrigation demonstration farms in Bhutan (total of 20) in 2016 was driven by the Engineering section of the Ministry of Agriculture

and Forests (MoAF) with the ACIAR demonstration orchard at Thangna acting as an early 'catalyst' and model for adoption.

There was a quick response to applying irrigation to trees during the critical flowering and early fruit set period in 2014. On average irrigated trees yielded 60 kg tree^{-1} as against only 35.6 kg tree^{-1} in the un-irrigated control trees. This is an increase in yield by 68.5 %. Similarly, irrigated trees gave an average of 778 fruit per tree while those of un-irrigated trees were 427. This gave a significant increase in farm income generated from the irrigated section of the property.

The selected orchard was considered one of the many declining orchards in Thangna before being adopted as a demonstration site. In 2013, basic management practices (fertilizer application, basin making and canopy management) were recommended and followed. In 2014, a section of the orchard was irrigated based on soil tensiometer results with a resultant improvement in monetary return [Nultrum = Nu. (1AUD = 50Nu)]

Table 3. Income trend of Thangna demonstration orchard

	Before adoption		After adoption	
	Baseline	Adopted as demo	No irrigation	With irrigation
Year	2011	2012	2013	2014
Nu.	18,000.00	10,000.00	70,000.00	150,000.00

Senior research officer, Tshering Penjor at ARDC Wengkhar fabricated micro irrigation systems with locally available, low cost materials. Recent innovations include the use of cheap emitters/micro-sprayers and burying main lateral lines to prevent physical damage to the infrastructure. Dr Penjor has also developed low cost electric fencing to exclude feral animals from horticultural blocks and this technology has been widely adopted across Bhutan. A range of irrigation emitters were also taken back to Bhutan for testing at the end of his month long training period in Australia during July 2015.
The centre also upgraded their mobile phone activated irrigation system, developed in 2014, to an internet and web-based control system to water their field evaluation site, propagation and mother tree nurseries.

Gibberellic acid (GA) evaluation for improving mandarin skin condition

The application of GA in autumn to citrus fruit can delay fruit colour development, improve rind firmness and quality, extend the harvesting window and improve post-harvest handling and shelf-life. An application of GA @10 ppm at 50-75% colour development on mandarins can delay rind ageing by up to 2 weeks. Although the application of GA is widely practiced in other countries, this technology was new to Bhutan.

The trials were established to a protocol developed for Bhutan by NSW DPI and aimed to demonstrate the benefits of applying a Gibberellic Acid (GA) spray to retard the rind development and prolong the post-harvest life of fruit. The trials were conducted by the National Post Harvest Centre (NPHC) and researchers at ARDC Wengkhar. The trial at ARDC Wengkhar was on fully bearing mandarin trees (Dorokha local selection) planted in 2001 in the germplasm block. The trial was conducted on single trees with three replicates. Six healthy trees were tagged as treatment trees (3 x GA and 3 x untreated controls). Gibberellic acid (GA) @ 10 ppm (2.5gm GA/ 100 L water) was applied in early December 2011 when fruit were 75% coloured. Fruit at the ARDC Wengkhar normally attains 75% rind colour from December onwards.

Analysis of data from the trials at ARDC Wengkhar in 2014 confirmed the GA applied to trees at 3-4 weeks prior to the normal harvest period slowed down rind development and resulted in firmer fruit at harvest and following post-harvest storage. This demonstration may provide Bhutan mandarin producers with a means of spreading maturity dates to take advantage of market opportunities.

Soil sampling and nutrition

Citrus soil/leaf sampling and analysis were conducted on demonstration orchards in Chukha, Sarpang and Dagana from 2013 to 2016 with additional leaf sampling in Lhuentse and Mongar during 2016. The data was used to confirm nutrient recommendations for citrus production in Bhutan. This project component was coordinated by project staff and the National Soil Services Centre (NSSC).

Table 4. General recommendation for fertiliser application to citrus in Bhutan

Plant nutrient	Non-bearing trees (g/tree/year)		Bearing trees (g/tree/year)		Time of application
	Nutrient	Fertilizer	Nutrient	Fertilizer	
Nitrogen	50-100	110g-220g Urea	150-250	330g-550g Urea	After harvest & prior to spring flush
Phosphorus	20-50	126g-315g SSP	50-100	315g-630g SSP	
Potassium	100-150	170g-255g MoP	250-350	425g-595g MoP	
FYM	To be applied based upon availability				

SSP = Single Super Phosphate, MoP = Muriate of Potash

Chemical fertiliser use is not common in Bhutan with farm yard manure (FYM) the main source of nutrients. The manure is carried in and applied to the soil around the tree or from tethering cattle to the tree for a defined period of time. The soil test results again highlight the low nitrogen and potassium levels in most soils tested and a need for additional inputs of organic and inorganic fertiliser. Cost and availability are two of the main reasons for lack of inorganic fertiliser use and also the cultural tradition of using animals to supply manure for crop production. There has also been a resistance to the application of chemical fertiliser because farmers consider it degrades the soil and is not a natural process. Citrus has a high demand for nitrogen and it is difficult, if not impossible, to supply that requirement from the application of cow manure. Supplementary Urea and mixed fertiliser (Sulphala) applied at the Thangna drip irrigation demonstration site improved the health of the trees and supported the improvements in yield and farmer income.

Survey of citrus growers in targeted areas of Bhutan, 2017

A 39 question survey was designed by the NSW DPI biometrics section in collaboration with Australian and Bhutanese project staff to be collected by DoA extension staff via farmer interview in seven citrus growing districts.

The survey aimed to assess current farming practice particularly in relation to activities conducted by Bhutan Department of Agriculture research and extension staff associated with the ACIAR citrus project (HORT/2010/089).

Project activities have been centred on selected districts, sub-districts and villages. The survey has collected data on farmer attitudes and mandarin management practices in those areas. These ‘proof of concept’ extension and research activities are then to be promoted on a wider scale in the citrus growing districts of Bhutan.

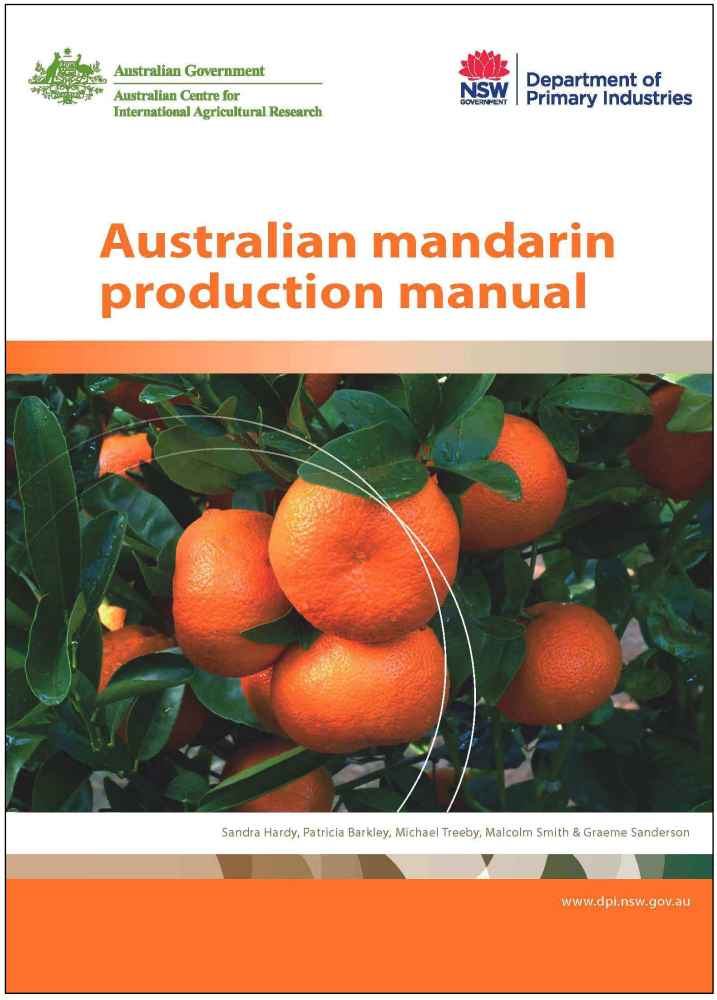
Statistical analysis of 241 responses will be finalised in March 2018 with a report provided to the Bhutan DoA and ACIAR.

Australian mandarin production manual

NSW DPI in association with the Australian Centre for International Agricultural Research (ACIAR) has produced a comprehensive mandarin production manual for Australia. The manual is an Australian output from two citrus projects in Bhutan with the first project; HORT/2010/142 'Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices' beginning in 2007. The current project; HORT/2010/089 'Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia' has completed in early 2018.

The manual was available as a hard copy in November 2017 and has received national citrus industry promotion beginning in February as a prelude to the beginning of the 2018 citrus season. The manual will also be formatted for inclusion on the NSW DPI website in 2018 which will give the capacity for future updating.

Figure 6. Australian Mandarin Production Manual published October 2017.



4. To build additional citrus research, development and production capacity of Bhutanese scientists, extension agents and citrus farmers

Professional training of Department of Agriculture and Engineering Division staff in Australia and Bhutan

The key component of the project was the professional development of Bhutanese staff in areas of high priority such as nursery, laboratory and irrigation management along with varietal development. Month long intensive training programs were provided in Australia for selected staff to improve their skills in these areas of citrus production. A specialised biometric training program was also provided in Australia for two officers on 'Trial design and biometric analysis' by Lorraine Spohr, NSW DPI biometrician. In addition in-country training programs were delivered to local staff by Australian project officers and consultants on 'Soil and water management', 'Nursery water management and 'Irrigation design and management for horticultural crops.'

Training in Australia

November 2013 – Citrus institutes, farm and industry tour to NSW and Victoria for new Bhutan project leader (Mr Lakey). Eleven days.

June 2014 – 'Irrigation design and management' (Nedrup Tshewang). One month.

May 2015 – 'Diagnostic laboratory and citrus repository' (Kinley Dorji). Three weeks.

June 2015 – 'Australian citrus industry and research facilities tour' by five scientists and project officers. Two weeks.

July 2015 – 'Citrus variety and rootstock evaluation' (Tshering Penjor), One month.

October 2015 – 'Biometric analysis and trial design' (Loday Phuntsho, Jigme). Two weeks.

Nov/Dec. 2016 – 'Commercial citrus nursery production' (Sangay Rinchen). One month.

Training in Bhutan

Feb. 2014 – 3 day workshop on 'Introduction to basic video production for agricultural officers' delivered by S. Falivene, NSW DPI at ARDC Bajo. (13 participants)

May 2014 – 4 day workshop on 'Irrigation design and management for horticultural crops' delivered by A. Lipman (Consultant) – Rural Solutions, SA and Jeremy Giddings, NSW DPI to agricultural engineers. (13 participants)

May 2014 - 2 day workshop on 'Irrigation and soil management' delivered by Australian project staff at ARDC Bajo. (15 participants)

November 2014 – seminar on 'Managing citrus biosecurity' delivered by Dr Nerida Donovan (Citrus pathologist), NSW DPI at the NPPC Thimphu, ARDC Bajo and National Seed Centre (NCR) Bhur. (40 participants). In association a seminar on 'Commercial nursery management practices in Australia' and a budding demonstration was delivered by Gary Eyles (Eyles Citrus) at ARDC Bajo and the NSC Bhur. (20 participants)

April 2016 - 2 day workshop on 'Irrigation and soil management' delivered by Australian project staff at ARDC Wengkhar. (26 participants)

April 2016 – 2 day workshop on 'Nursery water management' delivered by W. Yiasoumi (Consultant), Irrigation Australia and Jeremy Giddings/Graeme Sanderson, NSW DPI at Thimphu. (19 participants)

Training activities by Bhutan project staff for extension agents and farmers

Bhutan DoA staff received training from Australian staff and during citrus activities while in Australia. This new knowledge and skills were transferred to other extension officers and farmers during training activities schedules as part of their work programs. The ACIAR citrus project was an integral part of the national citrus strategy in Bhutan.

Training programs were often conducted as day long or as two day events and aimed to cover a range of orchard management topics with practical activities for famers and extension officers. Programs were organised around district centres (Dzonghags) and demonstration farms with training provided by local as well as specialist officers with citrus management expertise.

A selection of the training activities included:

2013

- 469 farmers in Tsirang given hands-on training in canopy management.
- 63 farmers in the Dunglagang geog of the Tsirang district trained on CCCF biology and management.
- 85 farmers in Tsirang trained by the NPPC for area-wide management pilot study.

2014

- Day long orchard management field days at demonstration orchards in Mongar and Lhuentse conducted by staff from the ARDC Wengkhar. 65 farmers received training on canopy management, fertilising citrus and irrigation practices.
- 329 households in the Drujeygang geog of Dagana district were trained on canopy, nutrient and pest/disease management with an emphasis on huanglongbing (HLB).
- Community based field days in Mongar and Lhuentse to educate the 52 farmers in attendance on fruit fly biology and management through dropped fruit collection, trapping and bait spraying.

2015

- 22 DoA extension officers trained over one day on canopy management at the demonstration orchard in Punakha by staff from ARDC Bajo.
- 30 farmers received training on nutrient management at the Punakha demonstration orchard.
- 63 farmers from Chukha district were trained by staff from ARDC Yusipang on orchard management including site planning, variety selection and harvesting.
- 53 farmers in Mongar and Lhuentse trained by staff from ARDC Wengkhar on citrus management including planting, fertiliser and canopy management.
- 27 farmers in Sarpang trained by staff at ARDC Bhur on improved methods of citrus cultivation and management.

2016

- Two-day training workshop was conducted on ‘Citrus nursery management’ at the National Citrus Repository, Mithun, Tsirang on the 11-12 April 2016 to equip nursery managers, quarantine personnel, researchers and extension officials with skills related to modern citrus nursery practices.
- 60 farmers from the Sarpang district were trained by the soil fertility unit from the National Soil Service Centre (NSSC) via a series of workshops on ‘Soil fertility and nutrient management in citrus’.

- Two-day training workshop on 'Citrus orchard and canopy management' was conducted for agricultural extension officers of Wangdiphodrang district on the 29-30 March 2016 at the citrus demo orchard in Damchoe, Kabjigewog in Punakha.
- Two-day 'Canopy management' training programs were conducted for farmers in 2015 in Tashiding, Tsendagang and Goshi geogs of the Dagana District.
- Two-day training workshop was presented at Tsirang by National Plant Protection Centre (NPPC) staff to better equip extension officials of Tsirang sub-districts on the 'Control and management of citrus pests'.
- A total of 1483 farmers were delivered training by DoA, NPPC and NSSC staff in 2016.

2017

- Two-day training on water conveyance options was provided to the extension officers of Dagana districts; farm manager and farm attendants of Kana citrus farm; and key citrus farmers of the Dagana district by Mr. Kinley Dorji and Mr. Phuntsho Wangdi, ARDSC Mithun on the 24-25th June 2017.
- Two day stakeholder workshop was organised to review citrus nursery standards, repository protocols and huanglongbing (HLB) issues in the nurseries and field and discuss the latest research work and views of stakeholders.
- Canopy management, nutrient, plant protection and irrigation management training conducted for the extension staff and farmers of Sarpang (11-15th Jan 2017) and Pemagatshel (13-17th Feb 2017) districts as part of technology transfer activities by ACIAR project officers.
- Short video under development for 2018 release on citrus canopy management. Footage compiled from canopy management training by Phuntsho Wangdi in Dagana and Chukha districts.

International Citrus Congresses

Three Bhutan Department of Agriculture project officers (Dorjee, Tshering Penjor and Kinley Dorji) attended the 12th International Citrus Congress, Valencia, Spain 18-23rd November 2012 along with project leader, G. Sanderson from NSW DPI. Verbal and poster presentation.

Two Bhutan Department of Agriculture project officers (Loday Phuntsho, Jigme) attended the 13th International Citrus Congress, Foz do Iguacu, Brazil 18-23rd September 2016 along with G. Sanderson and citrus pathologist Dr Nerida Donovan. Two posters presented.

Post Graduate study in Australia

Bhutan project staff achieved a high level of success with post graduate study in Australia during the term of the project.

1. Ms Namgay Om (NPPC) completed and awarded her PhD in 2017 at Western Sydney University.
   John Allwright Fellowship (JAF)
   Thesis: 'The Roles of Psyllids, Host Plants and Environment in the Aetiology of Huanglongbing in Bhutan'.

2. Mr Dorjee (Department of Agriculture Thimphu, ACIAR Project leader) completed his PhD at the University of Canberra in 2017 (JAF)
   PhD topic area: Biosecurity in Bhutan.

3. Sonam Gyletshen (ARDC Wengkhar) completed his Masters of Science by course work at Melbourne University in 2015 (JAF).

4. Kiran Mahat (NPPC) began a PhD at the Queensland University of Technology in 2015 (JAF)
   PhD topic: 'The use of entomopathogens in the control of Queensland fruit fly (QFF)'.

5. Ganja Singh Rai (ARDC Bhur) began a PhD at the University of Sydney in 2016 (JAF).
   PhD topic: 'Biology and Management of Phytophthora in selected horticultural crops in Bhutan'.

6. Mr Lakey (DoA Thimphu, ACIAR Project leader)
   Post graduate managerial studies, Perth, WA (Endeavour scholarship)
   Began June 2016 completed January 2018

7. Kinley Dorji (ARDC Bajo) will begin a PhD at the University of New England in 2018 (International Post Graduate Research Scholarship)
   PhD topic: 'Analysis of genetic variation and their root traits for abiotic stress tolerance in citrus'.
8. Jigme Tenzin (DoA Thimphu, ACIAR Project leader) will spend 4 months in Australia for professional development from August - November 2018 and be hosted by NSW DPI (Endeavour Executive Award scholarship).

All officers have or will return to Bhutan on the completion of their studies

8 Impacts

8.1 Scientific impacts – now and in 5 years

Production of disease free planting material is one of the biggest challenges facing the citrus industry in Bhutan. Hence, shoot-tip grafting for disease elimination has been undertaken in two facilities. Successful shoot-tips were created and are maintained in the mother block at the Agricultural Research and Development Centre, Wengkhar. The shoot-tip grafting technique was also undertaken at the National Citrus Repository, Mithun. These new skills will support the development of an effective disease elimination protocol and maintenance of high health status mother trees for the future supply of disease free budwood to propagation nurseries. The National Citrus Repository (NCR) established at the Mithun sub centre, Tsirang had a structural upgrade with ACIAR support and a protocol for its management and operation written in collaboration with Australian project staff in 2015. This protocol was further refined in 2016 and is the 'blue-print' for its operation into the future.

A second citrus repository facility has been established at the Agricultural Research and Development Centre (ARDC) Wengkhar in eastern Bhutan as a back up to the NCR at Mithun. In association with this facility a National Seed Centre (NSC) citrus propagation nursery is being established in Trashiyangtse at an elevation of 1780m asl. The location and elevation are a result of project outcomes that identified an elevation zone above which psyllid activity and HLB incidence was much reduced. HLB and *Diaphorina citri* (Asiatic citrus psyllid) occur at elevations up to 1400m but the incidence of both the disease (caused by '*Candidatus* Liberibacter asiaticus') and the psyllid are generally low to very low above 1200m. HLB is a serious problem below 1200m (possibly 1350m at Richina in Punakha) and loss of trees below 1200m is nearing 100%. Thus, *Diaphorina citri* is now uncommon below 1200m unless on nursery trees.

A second high altitude nursery at Paro in central Bhutan is also in a planning phase. The aim of the new, higher altitude nurseries is to provide high health status citrus seedlings to farmers in eastern and southern regions of Bhutan and support the re-development of citrus plantings impacted by HLB. To facilitate the nursery development two agricultural engineers travelled to Lhadak, India in November 2017 to view high altitude nursery structures and meet with Jain Irrigation Company engineers. Bhutan project leader Jigme Tenzin also went to Mumbai in December 2017 to have discussions with the Jain Irrigation Company on nursery establishment.

Huanglongbing (HLB) and other local Psyllid species

There was no evidence of transmission of the HLB pathogen '*Candidatus* Liberibacter asiaticus' ('*C*Las') by *Diaphorina communis* (black psyllid) from infected mandarin to mandarin or curry leaf. More than 200 *Cacopsylla heterogena* (green psyllid) adults or nymphs were tested for '*Candidatus* Liberibacter asiaticus' but the bacterium was only detected once in adults collected from seedling mandarin trees on the Talo-Walakha Road in Punakha at about 1400m. These trees were probably sourced from nurseries below 1200m more than 15 years ago.

Introduction and evaluation of Public Access Citrus Varieties (PACV) from Australia will enhance the diversity of citrus cultivars available in Bhutan. One recently fruiting navel orange selection (Cara Cara) introduced from Australia is identified for larger scale field evaluation. The project also supplied seven high health status processing orange varieties in November 2016 for the establishment of high health status mother trees to be held at the NCR Mithun and ARDC Wengkhar. These varieties would be the source of planting material to support the proposed establishment of a juice processing industry in eastern Bhutan. The active collection and maintenance of wild citrus germplasm will also help conserve the gene pool for possible future commercial use.

There are hybrid rootstocks under evaluation at ARDC Wengkhar created by crossing high altitude 'wild' germplasm with a commercial rootstock. The aim is to develop enhanced cold tolerance in a citrus rootstock.

Trials on use of Gibberellic acid (GA) for improvement of postharvest fruit quality have been conducted over 2 seasons at the ARDC Wengkhar and National Post Harvest Centre, Paro. The outcome has been that GA can slow the development of skin maturity and extend the harvest window for citrus in Bhutan.

Shortage of irrigation water is an issue in citrus growing areas, particularly eastern Bhutan. Therefore, one way to enhance water use efficiency was initiated at ARDC Wengkhar through the improvement of a mobile phone activated irrigation system into a more effective and user-friendly internet activated system. This would go a long way in achieving effective irrigation delivery systems and enhance water use efficiency not only at the Research Centres but also in the farmers' fields as a longer term objective. Similarly, the pressurised irrigation system (gravity fed) in demo-orchards has proven effective in improving the overall health, productivity and profitability of the orchards.

The area-wide Chinese Citrus Fruit Fly (CCFF) management program has been successful in reducing infestation levels in the pilot districts. Visits by plant protection experts and extension staff in 2015 and 2016 noted that many of the farmers who participated in the evaluation programs can now identify pests, are aware of the pest's biology and know the recommended management practices.

8.2 Capacity impacts – now and in 5 years

Additional capital funding provided by ACIAR allowed the upgrade of the insect proof facilities at the National Citrus Repository, Mithun. Work was completed in January 2017 to re-cover the structures which had degraded and were also damaged by a storm. The need to have a secure structure to maintain high health status citrus mother trees is a major requirement for the future development of the Bhutan citrus industry.

Figure 7. National Citrus Repository, Mithun March 2018.

Figure 8. Mother trees inside insect proof screenhouse.

It is also essential that staff have the skills to maintain the facility and a capacity to test the plant material for a range of citrus pathogens. The facility manager Mr Kinley Dorji spent a 3 week training period in Australia developing laboratory and diagnostic skills in citrus pathology and repository management. Mr Phuntsho Wangdi was appointed as the technical support officer at the NCR in 2017 and had one month's horticultural training in Australia during October 2009 and also led a Bhutan Department of

Agriculture tour group to Australia in June 2015. His role has been across the two ACIAR funded projects and he has expertise in the horticultural management of citrus and extension of this information to other staff and farmers.

Professional development training in both Australia and Bhutan has been aligned to the areas of most need for the development of the local citrus industry and implementation of scientific protocols. The identified areas for professional development included pest and disease management, nursery management and laboratory skills, irrigation design and management, variety improvement along with research trial design and analysis.

Key staff at the ARDC Wengkhar spent extended time in Australia and were supported by the ACIAR project included Tshering Penjor (variety evaluation, July 2015), Loday Phuntsho (Biometrics training, October 2015) and Sonam Gyeltshen (Master's degree completed 2015). These officers now provide a core group of expertise for citrus extension and research activities in Bhutan. A prime function is to impart their knowledge to the extension officers and farmers through training programs in the key citrus producing districts.

Nedrup Tshewang, Irrigation Engineer who had a one month training program in Australia on 'Irrigation design and management' during May 2014 has advanced in his roles and responsibilities in Bhutan. Nedrup is now a key officer in the design and implementation of pilot irrigation schemes in Bhutan as well as being given the responsibility for irrigation design and system installation at the King's Palace.

The final training program for a Bhutanese officer was completed in August 2017 related to attendance at the International Society of Citrus Nurseryman's Congress in Australia. Mr Lobzang Tshering is the manager of a new high altitude citrus propagation nursery in Trashiyangtse in eastern Bhutan. His two week training period involved visiting Australian citrus production nurseries and research farms in Queensland and Victoria, congress lectures and inter-acting other nurserymen from around the world. These experiences will assist him in his new role of nursery manager and add to the group of citrus professionals in Bhutan.

8.3 Community impacts – now and in 5 years

The citrus growing community in Bhutan is estimated at 22,000 farmers in 16 often isolated districts. These areas are divided into smaller village based sub districts (geog) and are serviced by a DoA extension officer who are required to provide advice and problem solve on all crops in their geog. The ACIAR projects have aimed to provide citrus management skills to both extension officers and research staff to assist them in supporting these farming communities. This has involved training in Bhutan and Australia and these officers then providing 'hands-on' training to other DoA officers and the farming community. Training has often been focussed on demonstration farms with the expectation that this new information will spread out to the surrounding communities. Change is gradual with citrus production a traditional practice with some resistance to adopt modern production techniques.

8.3.1 Economic impacts

Citrus is one of the most important export commodities earning Bhutan an average of $11.4m AUD pa between 2012 to 2016, it is also one of the least managed of enterprises in Bhutan. Orchards barely receive irrigation or nutrient inputs and tree management are low priorities for most growers. This has been further compounded by pests and diseases, particularly HLB, and has hence seriously affected the citrus industry in the country. The challenge for the DoA and ACIAR project has been to show positive outcomes to farmers with the adoption of improved orchard management techniques.

Financial benefits have been demonstrated to citrus farmers in a range of targeted activities directed by ACIAR project staff. The on-going community based control of Chinese citrus fruit fly (CCFF) has demonstrated positive effects on farmer incomes. Less fruit drop caused by fruit fly results in more saleable fruit. A study involving 270 farmers showed a reduction from 64% of fruit infested to 18% where a 2 weekly program of protein baiting was done from May to July and fallen fruit collected from November to mid-December as an area wide management initiative. Districts where active programs were implemented include Tsirang, Lhuentse and Mongar had reductions in fruit drop when compared to before the area-wide approach was adopted. These programs also involved the pre-training of farmers in fruit fly biology and management techniques. This has been economically analysed by the NPPC and presented to farmers and at conferences outside of Bhutan.

Irrigation training is now incorporated into farmer training programs as the development of gravity fed irrigation systems continues to be adopted in Bhutan. The Department of Agriculture collected yields and economic return data from the initial demonstration site at Thangna, Dagana which showed an increased yield and economic return from strategic application water via drip irrigation. There was almost a two-fold increase in monetary returns, based on a higher fruit set and individual fruit weight (up 11%), from trees irrigated at flowering and early fruit set as compared to those dependent on natural rainfall. This pilot site has helped to drive the expansion and adoption of gravity fed drip irrigation for citrus orchards in Bhutan.

Direct and significant impacts of various interventions by the Department may not be immediate and visible. However, there is progress. For instance, in Drujegang (Dagana), both production and cash income increased as a result of the mitigation programs supported by the project in advocating area-wide orchard management programs. These activities included canopy management, weed control, basin making, fertiliser management along with collection and disposal of dropped fruit. Annual income from citrus increased from 33% in 2012 to over 50% in 2014 following area-wide management advocacy programs.

8.3.2 Social impacts

Bhutanese farmers are generally conservative, follow traditional practices and are often resistant to change. Income derived from citrus is a major component of the cash earned by farmers which is used for educating children and other living expenses. The Department of Agriculture has undertaken targeted extension and group training programs to introduce new technologies and help develop cooperative approaches to improving farmer incomes. The successful area-wide approach to Chinese citrus fruit fly management began in 2013 in the Tsirang district with the community based approach to pest and disease management extended to other regions. Installation of drip irrigation has also clearly demonstrated the financial benefits of applying water to citrus trees during periods of water stress due to low natural rainfall. This has acted as a catalyst for the expansion of these systems to other districts of Bhutan.

The community focused approach has been demonstrated to be the best model for achieving improved economic and social outcomes for farmers. Group and community training is the most efficient method to impart knowledge and skills to farmers in the widely distributed and often isolated citrus growing districts in Bhutan. The community approach, facilitated by the Department of Agriculture, is seen as a way of encouraging farmers to interact with each other, develop social relationships and work for the benefit of their immediate family and the local community.

8.3.3 Environmental impacts

The Bhutan government has a policy of reducing chemical inputs to agriculture with an ultimate aim of organic production. ACIAR project supported trials have shown that the severity of Chinese citrus fruit fly damage to citrus can be reduced with the collection

and destruction of fallen fruit along with targeted use of a protein bait and chemical. Work is also continuing on the selection and testing of attractant baits to lower the fruit fly problems in an orchard. These are more environmentally appropriate methods that fit the government policy and do not involve a whole tree chemical spray program.

The ACIAR project has proposed a zone of 1200m asl above which Asian psyllid activity and the severity of huanglongbing (HLB) infection is reduced. The establishment of new, higher altitude citrus propagation nurseries at Trashiyangtse and Paro is an outcome of the project's pest and disease management component. Control of the psyllid and HLB at low altitudes will be very difficult in Bhutan due to the small size of the citrus blocks, advanced age of the majority of trees and lack of chemical control options. The future strategy would be to move citrus production to a higher altitude zone, propagate with known health status citrus material and ideally on a rootstock to achieve earlier fruit production.

The recent development of gravity fed irrigation systems for citrus production is utilising an abundant environmental resource. The efficient use of this natural resource has been demonstrated to provide economic benefits to the farmer with limited impact on the environment. Skills have been developed by local staff in the design and management of drip irrigation systems from training delivered in Australia and Bhutan. Electronic skills developed by a senior research officer at the ARDC Wengkhar are also demonstrating the opportunities for Bhutan to schedule and control drip irrigation systems with electronic web based, relatively cheap technologies.

8.4 Communication and dissemination activities

Media

A live panel discussion was organised on National TV News Channel (Bhutan Broadcasting Service - BBS Corporation) in mid-March 2014 to educate and create mass awareness on citrus disease and management aspects. The program also informed the Bhutanese viewers on the various on-going activities including contributions by the project. Lakey, the Bhutan Project Leader (and Coordinator for the National Citrus Program), Kinley Dorji (Sr Research Officer, ARDSC Mithun) and Dr Thinlay (NPPC) were the panel members.

The area wide CCFF management program in Tsirang in April 2014 was covered extensively by BBS TV. Kiran Mahat (Sr Plant Protection Officer, NPPC) and the Bhutan Project Leader were interviewed as part of the coverage which also sought the views of the participating farmers on camera.

A 3 day workshop was conducted by Steven Falivene at Bajo RDC during a scheduled visit from the 17th – 22nd February 2014. Thirteen officers were involved in the workshop with 4 having a direct role as Bhutan ACIAR project co-operators. The aim of the workshop was to provide participants with skills to confidently prepare, film and edit a training video suitable for YouTube publication.

BBS TV produced a documentary on the Citrus Repository at Mithun. The program which was aired several times and covered all aspects of the citrus repository and the strategies and initiatives the project and the DoA have been putting in place to ensure the development and sustainability of the citrus industry in Bhutan. Kinley Dorji, Sr Researcher with the ARDSC Mithun appeared in the program that was filmed at Mithun and also featured the project's interventions at pilot orchards in Tsirang.

A canopy management and related orchard practices training video is in production and will be available for release and use by mid-2018.

Reviews

A mid-term project review was conducted by Dr Richard Markham in Bhutan from the 11th - 19th April 2015.

The end of project review was conducted in Australia at the Elizabeth Macarthur Agricultural Institute on the 6th October 2016 with Richard Markham, Richard Brettell (ACIAR) and Andrew Beattie (UWS), Nerida Donovan and Graeme Sanderson (NSW DPI). Richard Markham also visited Dareton Primary Industries Institute on the 24th October 2017 to view project activities conducted on site and meet with Graeme Sanderson. The in-country review was conducted by Richard Brettell, Kuhu Chatterjee (ACIAR) and local Bhutan consultant, Nidup Penjor from the 28th October to the 6th November 2016. The review team visited trial sites, the National Citrus Repository, met with senior Department of Agriculture officials, the Minister of Agriculture and attended a 1½ day workshop on project activities and outcomes.

Conference presentation of project outcomes

- Project staff (Dorjee, Tshering Penjor and Kinley Dorji – Bhutan and Graeme Sanderson, – Australia) attended the 12th International Citrus Congress, Valencia, Spain, 18th - 23rd November 2012 and presented one verbal presentation and one poster.

  Poster: 'Gaining experience with exotic pest and disease threats to Australia through collaborative work in Bhutan'.

  Verbal presentation: 'New citrus variety evaluation in Australia 2005-2012'.

- Project staff (Jigme Tenzin, Loday Phuntsho – Bhutan and Graeme Sanderson, Nerida Donovan – Australia) attended the 13th International Citrus Congress, Foz do Iguacu, Brazil, 18th - 23rd September 2016 and presented 2 posters.

  Poster 1: 'A Health Check on the Bhutanese Citrus Industry'

  Poster 2: 'Evaluation of citrus selections arising from natural mutation in Australia'

- A poster was presented on 'Area-Wide Management of Chinese Citrus Fruit Fly in Tsirang, Bhutan Using Protein Bait Sprays and Orchard Hygiene' by PhD student Kiran Mahat et al., at the Third FAO/IAEA International Conference on Area-wide Management of Insect Pests. Vienna, Austria 22nd – 26th May, 2017. The study was supported through the ACIAR project on area-wide management of fruit fly in Tsirang. It demonstrated that the Chinese citrus fruit fly could be effectively managed through a community-based approach and by employing environmentally friendly management strategies like protein baiting and crop hygiene.

Booklet, Manual and Phenology poster publications

- The mandarin phenology poster developed for Bhutan has been revised in 2013 to include the timing of key management practices. The management practices have been depicted using a series of pictograms. One thousand copies of the poster produced for distribution to farmers and DoA personnel.

- The National Citrus Program developed a citrus nursery technical document with input from Australian team member Dr Nerida Donovan (Citrus pathologist). The manual aims to standardise and document technical as well as regulatory procedures in the production of high health status citrus planting material as well as re-emphasising the important functional roles of respective agencies involved in the nursery production chain.

- The National Plant Protection Centre (NPPC) released a publication on 'Citrus Pests and Diseases management' - 2017 and a website and database on 'Pests in Bhutan' was also developed with Australian volunteer support.

- 'Production Guide for Mandarin Orchards in Bhutan' revised in 2016 and to be updated with new information in 2018.
- The 'Australian Mandarin Production Manual' was released in October 2017 with a limited print run and will be formatted for placement on the NSW DPI website in 2018. The 320 page manual will also have general application as a text reference for Department of Agriculture use in Bhutan.

Scientific papers

The research program on area-wide CCFF management was published in the proceedings of the *9th International Symposium on Fruit Flies of Economic Importance* held in Thailand, May 2014 by Kiran Mahat et al. 'Field evaluation of attractive lures for *Bactocera mimax* (Enderlein) (Diptera:Tephritidae), for use in spot sprays in Tsirang, Bhutan.

A paper was published by project officers during 2016 on 'A Supply of Healthy Germplasm is the Key to Survival of the Bhutanese Citrus Industry', Donovan et al. *Journal of Food, Agriculture & Environment (2016) Vol.14 (3&4), 2 3 - 2 8* .The paper highlights the need for healthy nursery trees and the adoption of improved management practices to mitigate the effects of huanglongbing on the Bhutan citrus industry.

A paper was published in 2016 in the Agriculture and Food Security Journal highlighting the departmental and project efforts to improve citrus management in the Dagana region of southern Bhutan – 'Adoption of improved orchard management practices; a micro study from Drujegang growers, Dagana'. One of the current approaches to citrus development in Bhutan is the 'Focus Village Approach'. This involves a community being supported by the DoA extension and research sections to improve management technologies as well as specialise in a specific commodity such as a new citrus variety supplied from Australia.

9 Conclusions and recommendations

9.1 Conclusions

The Bhutanese citrus industry faces a number of challenges to reach the vision of the national government for increased citrus export income and organic agricultural production. The project targeted those areas of identified need to address the most significant horticultural production and staff capacity issues.

The establishment, maintenance and regular testing of mother tree source material now has a focus at the National Citrus Repository (NCR). The rejuvenation of the industry must come from using planting material of a known health status. Bhutan Department of Agriculture staff were trained in Australia and Bhutan on laboratory diagnostics, repository and nursery management and an operating protocol written. The insect proof screenhouse has been upgraded and diagnostic testing of trees done in Australia and now Bhutan.

The testing of locally available mix components to develop an improved potting media for citrus seedlings was conducted at the NCR and ARDC Bhur. An aerated potting mix based on sand and composted sawdust resulted in improved plant growth with less likelihood of root decline. A large range of high health status, public access varieties were introduced from Australia for evaluation with the aim of expanding the choice of varieties for farmers and lengthening the citrus season past 4 months of the year.

The PhD work on psyllids in Bhutan has identified a zone (1200m asl) above which the Asiatic psyllid (vector) activity is much reduced as too is the incidence of HLB. This has resulted in the establishment and planning for two large citrus propagation nurseries to be developed at approximately 1700m asl. There was also no evidence found that the black psyllid was another vector of the HLB bacterium likely to affect citrus trees.

The project demonstrated the effectiveness of powdery mildew suppression with the use of regular sulphur sprays which could fit into an organic production system. Area wide Chinese citrus fruit fly management strategies of fruit collection and disposal along with bait spraying and trapping gave yield and economic benefits to the farmers involve in the pilot studies.

The introduction of drip irrigation at a demonstration farm at Thanga, Tsirang district in 2013 and strategic watering during low rainfall periods gave immediate yield and monetary benefits to the cooperating farmer. This positive result has helped to stimulate the expansion of micro-irrigation systems to other districts of Bhutan with irrigation of horticultural crops a priority of the national government.

Demonstration sites were established in 7 districts and acted as a focal point for farmer training on canopy management, fertiliser application, pest and disease control and irrigation management as well as increasing the skills of DoA extension and research staff.

Bhutan staff updated the ‘Production Guide for Mandarin Orchards in Bhutan’, developed a booklet on ‘Citrus Pests and Diseases Management’ and wrote a citrus nursery and repository management protocol. Current and former NSW DPI staff also published an ‘Australian Mandarin Production Manual’ in 2017.

Bhutan DoA officers received extended training periods in Australia in the priority areas of irrigation, laboratory skills, nursery management, variety development and biometrics. Project staff were also able to attend international citrus congresses in Spain (2012) and Brazil (2016) along with an international citrus nurseryman’s congress in Australia (2017). Eight Bhutan DoA officers were awarded, began or completed post-graduate studies during the project term with four recently returning to roles in the Bhutan Department of Agriculture.

9.2 Recommendations

The 15 recommendations outlined from the first Bhutan project HORT/2005/142: *'Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices (2007-11)*' were predominantly achieved in the current project.

The following recommendations are suggested to 'build' on the outcomes of the second project and maintain citrus production expertise in the Bhutan Department of Agriculture for the benefit of citrus farmers and local communities.

- There is now a core of trained and experienced staff with citrus expertise in the DoA. This needs to be maintained with financial support and not lost through reallocation of roles and changes to government priorities or policy.
- Protocols developed and documented for the management of nurseries and the National Citrus Repository need to be enforced and monitored to help guarantee a source of high health status propagation material for re-development of the Bhutan citrus industry.
- The industry needs to expand at higher altitudes and adopt rootstocks to bring trees into fruit production earlier than trees propagated as seedlings. Government policy direction is required to stimulate this change with a tree subsidy cost one avenue to assist farmers. The Department of Agriculture should actively investigate potential alternative crops for farmers to adopt at lower altitudes where citrus production has been badly affected by HLB.
- The DoA develops a multi-media extension effort for the information generated from this project to reach as many citrus farmers as possible. This would include strategies such as TV, short video, YouTube, phone message alerts, regional workshops and focus village initiatives.
- The use of demonstration farms as an extension resource has proven successful and should be retained.
- The economic benefits of practice change have been demonstrated during the project and should be a key component of any future extension programs.
- Research and extension links between Australia and Bhutan should be maintained, especially in the areas of nursery management, plant diagnostics, irrigation and diversification of the citrus varieties available to Bhutanese citrus farmers.

10 References

10.1 References cited in report

- Australian Citrus Tree Census 2016, Citrus Australia Ltd., Mildura, Victoria.

10.2 List of publications produced by project

Scientific

- Sanderson, G.P., Creek, A., Lacey, K and Wallace, M. (2014). New citrus variety evaluation in Australia 2005-2012. *Acta Horticulturae in Proceeding of the 12th International Citrus Congress, Valencia, Spain, Nov. 2012.*
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- Om, N. (2017). The role of psyllids, host plants and environment in the aetiology of huanglongbing in Bhutan. PhD thesis. Western Sydney University.

Australian project team developed publications for DoA use in Bhutan

- 'Citrus Phenology poster' (2013) to show citrus growth phases and management activities related to the crop cycle.
- 'Gibberellic Acid (GA) trial design and protocols' (2013) for evaluation of the growth regulator for improving mandarin skin condition.
- 'Potting mix trial design and protocols' (2014) for the evaluation of locally available components (sand, manure, forest compost, sawdust and their combination).
- 'Air Filled Porosity (AFP) technique, standards and equipment' (2014) for determination of air content in a potting mix.

Bhutan DoA project team extension publications

- 'Citrus nursery and repository management protocols' (2014) developed in collaboration with Dr Nerida Donovan (Citrus Pathologist).
- 'Production Guide for Mandarin Orchards in Bhutan' (revised 2016). Lakey, Dorjee, Tenzin, J., Dorji, K., Wangdi, P and Sanderson, G.

- 'Citrus Pests and Diseases Management' booklet (2017), National Plant Protection Centre.

Publication for Australia by current and past ACIAR project officers

- Australian Mandarin Production Manual (2017). Hardy, S., Barkley, P., Treeby, M., Smith, M. and Sanderson, G.

11 Appendixes

11.1 Appendix 1: Survey questionnaire of growers in the districts of Dagana, Tsirang, Lhuentse, Punakha, Mongar, Sarpang and Chukha

ACIAR PROJECT | HORT/2010/089.INTEGRATED CROP MANAGEMENT

SURVEY OF CITRUS GROWERS IN TARGETED AREAS OF BHUTAN, 2017

Foreword

The 2017 survey aims to assess current farming practice particularly in relation to activities conducted by Bhutan Department of Agriculture and Forests research and extension efforts associated with the ACIAR citrus project (HORT/2010/089).

Activities have been centred on selected districts, sub districts and villages. The survey will collect data on farmer attitudes and mandarin management practices in those areas. These ‘proof of concept’ extension and research activities are then to be promoted on a wider scale in the citrus growing districts of Bhutan.

Initial survey (2007) aims

(Project Number: HORT/2005/142 October 2008)

2007 survey aims:

- identify the citrus production practices
- identify the knowledge of the respondents
- identify some of the needs of citrus farmers
- develop research and extension programs necessary for maintaining and improving the productivity of the citrus industry of Bhutan

Key findings

Table 1 Key findings of survey conducted in 2007

Finding	Action	Indicator of action	End user/farmer response for positive outcome
Aged trees High % (32) citrus trees past peak production	Promotion of citrus replant programs	Evidence of promotion	Tree age audit
Source of citrus trees On-farm propagation popular	Citrus improvement scheme using clean, true-to-type (certified) planting material	Citrus improvement scheme developed	Plantings of certified material
PESTS: Chinese citrus fruit fly Recommendations for Chinese citrus fruit fly control not being followed (low incidences of spraying and high incidences of fruit drop)	Program to increase awareness of recommendations for control of Chinese citrus fruit fly, esp. backyard fruit growers	Evidence of promotion	Awareness and implementation of correct spray regimes, leading to decrease in pest population
Fallen fruit disposal Localised high crop losses where fallen fruit fed to livestock	Additional investigation in districts where this practice occurs	Details of investigation	Practice reduced or stopped
DISEASE: Citrus greening disease Limited awareness of Huanglongbing (citrus greening disease) and the psyllid insect vector (Diaphorinia citri), esp. backyard citrus farmers	Awareness campaign developed and implemented on the identification, spread and management of Huanglongbing	Evidence of campaign relayed to growers	Increased knowledge of disease and vector. Increased incidence of spraying
DISEASE: Powdery mildew High rating of powdery mildew as most detrimental disease for Bhutanese citrus. Lack of knowledge on how to control the disease.	Research appropriate control measures	Appropriate control measures for citrus production found	Farmers implementing control measures
Fertiliser practices High rate of organic fertiliser application	Investigate the nutrient status of commercial citrus trees to assess if organic fertilisers used provide adequate nutrition	Nutrient status of commercial citrus trees/fruit documented	Growers receive recommendations on optimum rate and timing of fertiliser application

Finding	Action	Indicator of action	End user/farmer response for positive outcome
Irrigation practices Low incidences of irrigation	Enable access to irrigation water supplies for commercial growers	Irrigation systems set up and used	Higher incidence of irrigation of citrus trees
Spray equipment Majority of respondents own and use spray equipment, but lack of information vis. appropriateness and chemical use training	Further investigation into the most suitable spray equipment for use in citrus orchards in Bhutan	Spray equipment suited to Bhutan's terrain and farmer's budgets	Advice received on recommended spray equipment and training on safe and effective use of chemicals received

2017 survey objectives

Aim: to document impact and KASA criteria in target areas related to project activities by the Ministry of Agriculture and Forests (MoAF)

[KASA refers to knowledge, attitudes, skills and aspirations that influence the adoption of selected practices and technologies to help achieve targeted social, economic and environmental outcomes]

Overall objective: improve mandarin productivity and sustainability in Bhutan

Table 2 Key issues to address in survey 2017

Issue	Query	Indicator of impact	KASA	Outcome/output
Aged trees	What is the age profile of trees in 2017?	Tree age audit **Q4–5b**	*Practice*: greater proportion of younger trees planted	Younger trees
Source of citrus trees	What is the main source of trees for planting in 2017?	More trees sourced from production nurseries **Q6**	*Practice:* plantings of certified material, rather than own propagation	New trees sourced from professionally run citrus nurseries
Fruit drop	Awareness of and extent of fruit drop. Methods of control of fruit drop. Targeting of backyard growers	Less incidence of fruit drop recorded; crop loss reduced, knowledge of cause; incidences of spraying increased **Q7–16**	*Skill*: Control of the cause of fruit drop *Knowledge*: cause of fruit drop; method to control fruit fly, esp. by backyard producers *Practice*: collection of dropped fruit	Fruit drop collection becomes an orchard management practice
PEST: Chinese citrus fruit fly	Do they have/have they had fruit fly larvae in fruit? Spraying regime Fruit fly population	Recognition of fruit fly larva **Q14** Increase/decrease of incidence of fruit fly Correct spraying regime (timing and current recommendation)	*Knowledge*: recognition of fruit fly larva *Attitude, skills*: spraying regime implemented	Fruit fly impacts in 'area wide management' focus areas shown to be less severe and gives economic benefit to farmers
Fallen fruit disposal	Is fruit being disposed of as recommended by the MoAF?	More frequent collection and more burying/burning; less fed to livestock **Q17–19**	*Practice*: high incidence of fruit picked up; feeding to livestock reduced/stopped	Correct disposal of fallen fruit a standard management practice
DISEASE: Citrus greening disease	Is there high awareness of the disease and vector.	Knowledge of disease and vector (identification, spread and management), ID of citrus greening and vector **Q20–27**	*Knowledge*: correct ID of vector and disease; especially amongst backyard growers *Practice*: spraying for control occurring; follows MoAF recommendations	Management/control and understanding of citrus greening disease
DISEASE: Powdery mildew	Appropriate control measure found, advised of and implementation begun	Control method for powdery mildew promoted and in use **Q28-30**	*Knowledge*: correct ID of powdery mildew *Practice*: farmers implementing control measures	New research on management/control options for powdery mildew extended to farmers by MoAF
Fertiliser practices	Are current fertiliser applications satisfying tree's nutrient needs?	Growers applying both organic and inorganic fertiliser **Q31-33**	*Knowledge*: nutrient needs *Skill*: applying correct fertiliser at correct rate *Practice*: optimum	Improved nutrient status of trees and fruit yield

Issue	Query	Indicator of impact	KASA	Outcome/output
			fertiliser application	
Irrigation practices	Adoption of irrigation systems on commercial citrus farms	Irrigation applied; advanced irrigation systems operating **Q34-35**	*Attitude*: key growth period watering of trees when required *Knowledge*: key period watering improves yield *Skills*: irrigation capability *Practice*: advanced watering systems utilized and meeting moisture needs of trees to optimize yield	Irrigation systems adopted and farmer knowledge of the benefits of irrigation
Other management practices	Adoption of orchard management systems on commercial citrus farms	Canopy managed; pruning; weed control **Q36-39**	*Attitude*: additional inputs to achieve economic returns *Knowledge*: correct timing of activities *Skills*: developed through extension support from MoAF *Practice*: optimum tree management	Management activities adopted to improve tree health, nutrition, productivity and economic returns

Targeted Citrus Grower Survey: Bhutan 2017

COLLECTION OFFICER:_____

DZONGKHAG:_____ ***GEOG:***_____

❑ Survey questions

1. Farm location: _____
2. Name of orchard owner: _____
3. Number of mandarin trees: _____

Tree Age Profile

4. Age of trees

Tree age	Number of trees

5. Are you planning to plant any more mandarin trees? Yes □ No □ *Go to Q5b*

5a. How many trees and when will you plant?

Go to Q6

5b Why won't you be planting any more mandarin trees? *(Tick all that apply)*

Too expensive □ Hard to access □ Other □ _____

Go to Q7

Source of mandarin trees

6. Where will you purchase/get your citrus trees from? *(Tick all that apply)*

Buy from Druk Seed □ Buy from local nursery □ Grow your own □

6a. Will your new trees be grown from seed or grafted onto rootstocks? *(Tick all that apply)*

Grown from seed □ Grafted Rootstocks □

Fruit drop

7. Do you experience Fruit Drop? Yes □ No □ *Go to Q*14

8. What do you think is causing your fruit drop? *(Tick all that apply)*

Fruit fly □ Shield/stink bug □ Don't know □ Other □ _____

9. What is your average annual crop loss due to Fruit Drop?

Less than 10% □ 10-30% □ 31-50% □ 51-70% □ More than 70% □

10. Do you spray chemicals to control Fruit Drop? Yes □ *Go to Q12* No □

11. List reasons why you don't use chemicals to control Fruit Drop.

Go to Q14

12. What type of sprays do you prefer to use?

Cover sprays □ Splash Bait sprays □ Bait & cover sprays □

13. What is your spray program for controlling fruit drop?

Chemical	**Rate**	**Timing**

14. Can you recognise Fruit Fly larvae in your fruit? Yes □ No □

15. Do you cultivate the ground under your trees to disturb fruit fly pupae in the soil?
Yes □ No □ Go to Q17

16. In what months of the year do you cultivate under your trees?

_____

Fallen fruit disposal

17. Is fallen fruit picked up? Yes □ No □ *Go to Q20*

18. At what interval do you pick up your fallen fruit?

Weekly □ Fortnightly □ Monthly □ Other□

19. What do you do with the fallen fruit? *(Tick all that apply)*

Bury it □ Burn it □ Feed it to livestock □ Other □ _____

DISEASE: Citrus greening disease (Huanglongbing – HLB)

20. Have you heard of citrus greening? Yes □ No □ Go to Q24

21. Do you have citrus greening disease on your farm?

Yes □ No □ Go to Q23 Don't know □ Go to Q23

22. How do you know you have citrus greening?

23. Do you know that an insect carries citrus greening disease? Yes □ No □

24. The name of the insect carrying the disease is the Asiatic citrus psyllid. (Refer to photo)

Have you noticed this psyllid in your orchard? Yes □ No □ Go to Q28

25. Do you spray to control this psyllid? Yes □ Go to Q27 No □

26 Why don't you spray? _____

Go to Q28

27. What is your spray program for controlling this psyllid?

Chemical	Rate	Timing

DISEASE: Powdery mildew

28. Do you have powdery mildew on your trees? Yes □ No □ Don't know □

29. Do you spray to control it? Yes □ No □ *Go to Q31*

30. What chemical do you spray and at what rate?

Chemical	Rate	Timing

Fertiliser practices

31. Do you fertilise your trees? Yes □ No □ *Go to Q33*

32. What is your fertiliser program for the year?

Fertiliser	Amount/Rate (g/tree)	Application time	Method of application
Urea			
Suphala			
SSP			
Farm Yard Manure (kg/tree)			
Other fertilisers (name)			

Go to Q34

33. Why don't you use fertilisers? *(Tick all that apply)*

Not available □ Too expensive □ Degrades the soil □

Have no knowledge of fertilisers □ Other □ _____

Irrigation practices

34. Do you water your trees? Yes □ No □ *Go to Q36*

35. How do you water your trees? *(Tick all that apply)*

Water can □ Hose □ Furrow □ Drip □ Other □ _____

Other management practices

36. Do you use any of the following management practices in your citrus orchard?

(Tick all that apply)

Basin making □

Clearing of vegetation/weeds □

Removing dead wood □

Pruning □

Mulching □ Other □ _____

7. List the 3 most important insect pests and the 3 most important diseases that cause the most damage to your mandarin fruit or trees:

Rating (1= most important)	**Pest**	**Disease**
1		
2		
3		

38. Do you use any other sprays on your farm? Yes □ No □ Survey complete

39. Please list these other sprays

Chemical	**Timing**	**Reason**

Survey complete

Thank you for answering these questions which will help to identify mandarin growing practices in Bhutan and determine issues that need to be addressed.