Australian Government
Australian Centre for International Agricultural Research

Final report

project	**Integrating soil and water management in vegetable production in Laos and Cambodia**
project number	SMCN/2014/088
date published	21st September 2020
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approved by	Dr James Quilty
final report number	FR2021-033
ISBN	978-1-922635-35-8
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

Contents

1 Acknowledgments

We are very grateful for the collaboration and access to the land provided by our participating vegetable farmers in Lao PDR and Cambodia.

For their personal contributions to the project, we acknowledge and greatly appreciate the project team, past and present: There have been about 25 core project team members throughout the project with about eight from Australia, ten from Lao PDR and eight from Cambodia.

For operation, contracting, funding, institutional and administrative support we acknowledge the commissioned organisation: University of Southern Queensland, the collaborating institutions in Australia: the University of Tasmania and the University of Queensland, and the partner organisations: the National Agricultural and Forestry Research Institute Horticulture Research Centre (NAFRI HRC), National University of Laos (NUoL) and the Clean Agriculture Development Centre (CADC) in Lao PDR and the Cambodian Agricultural Research and Development Institute (CARDI) in Cambodia, as well as provincial and district agriculture departments.

Dr Alice Melland led the project from Jan 2016 after Associate Professor Colin Birch sadly passed away. Mr Erik Schmidt (USQ) provided mentorship and also led the project from April 2017-April 2018 while Alice took maternity leave. Dr Stephen Ives (UTas) was co-leader of the project from beginning to end. The Cambodia component of work was initially led by Dr Vang Seng and is now led by Dr Sarith Hin, both from CARDI. The Lao PDR component of work was led by Dr Bounneuang Douangboupa from NAFRI HRC. The NUoL project leader is Assoc. Prof. Fongsamouth Southammavong and the CADC leader has been Mr Bouthsakone Inthalangsee after Dr Thongsavath Chanthasombath also sadly passed away in early 2016.

For knowledge sharing and value adding opportunities we acknowledge our sister ACIAR projects ASEM 2012/081 and SMCN 2016/237. We also appreciate the many other individuals, NGO representative and private sector operators who have informed and/or disseminated the project research over the years.

For commissioning, advocacy and oversight of the project, we acknowledge Dr Robert Edis (2015-2019) and Dr James Quilty (2019-2020), Research Program Manager, Soils and Land Management, ACIAR.

2 Executive summary

The 'Integrating soil and water management in vegetable production in Laos and Cambodia' project was undertaken because improved management of soil and water resources presented a major opportunity to sustainably enhance vegetable yields, productivity and household economies in Lao PDR and Cambodia. The objectives of the project were to analyse input supply chains and identify opportunities to improve their functioning and performance (Objective 1), to design and implement strategies for practice change and improvement of livelihoods (Objective 2), to develop viable soil management practices (Objective 3) and to improve irrigation (Objective 4) of smallholder vegetable production. To meet these objectives, the project team undertook activities including supply chain mapping, livelihoods analysis surveys, participatory impact pathways analysis, network surveys, crop trials and demonstrations, stakeholder training, field days, scientific publication, collaboration across ACIAR projects, and development of extension materials. The research was conducted in Vientiane Capital and Champasak provinces in Lao PDR, and in Siem Reap and Kampot provinces in Cambodia. The project budget was AUD 1.63 million and was conducted from September 2015 to June 2020.

Field trials revealed that yields of leafy vegetables can be increased by up to 50% by applying standard NPK recommendations while reducing fertiliser input in most cases. They also showed that even small applications of lime raise leafy vegetable yields by up to 100% within a crop cycle, particularly on sandy lowland soils in Cambodia. However, lime use is limited by supply and cost. Lime is available in Lao PDR but not widely used. Trials demonstrated that irrigating to predicted crop demand (using FAO ET_c based estimates) saves ~60% of water, and therefore time and labour, without yield penalty and with potentially small yield increases, giving a 2-3 fold increase in water use efficiency.

Supply chain studies identified that some farm input product labels had no guidance on use or the information was not in the local language. A strong reliance by farmers on local suppliers, built on trust and proximity, brought risks in terms of dependency on price and product availability but also provides an opportunity for local suppliers to be a source of technical information. Livelihoods analysis identified that a significant numbers of farmers had limited schooling and that in Cambodia, a large number of male farmers worked both on and off the farm. Farmer to farmer exchange played a critical role in practice adoption by farmers in Lao PDR, whereas family members were a more important source of information for Cambodian farmers. The project also identified that in Lao PDR, adoption of 'organic' standards is constrained by a lack of price incentive on the domestic market.

Over 35 technical reports have been prepared by the Lao, Cambodian and Australian partners and 17 training workshops were conducted to build research and extension capacity. Women comprised 30% of the workshop participants. To disseminate the research findings and to engage farmers, 39 field days or training events were held across the four provinces. These field days attracted 850 farmer attendees as well as over 60 other stakeholders. At the extension events, the median percentage of attendees that were female was 31% in Lao PDR and 77% in Cambodia.

Within the life of the project, a significant impact in Cambodia was that adoption of lime recommendations by farmers participating in the project doubled within Siem Reap (to 61%) and increased seven-fold within Kampot (to 49%) Province. In Lao PDR, irrigation scheduling practices were modified by at least 50 farming families in a scale-out village. Recommendations for future actions to scale-out the project's impact and for future research and extension in vegetable production were developed (see section 9).

If vegetable farmers apply lime, follow standard fertiliser guidelines and adjust irrigation volumes then yields may increase by 50-100% and livelihood gains are possible. In addition, reductions in water use per crop may allow an extended production season in regions where dry season water supply is limited, or an expansion of production area with the labour saved from changed irrigation management devoted to increased production.

3 Background

Lao PDR and Cambodia are developing economies seeking to improve crop yields for domestic consumption and to supply export markets to support their policy emphases on improving food security, overcoming rural poverty and enhancing economic development. Capacity development, equity, employment and sustainable economic growth are major strategies to reduce poverty. Women play a key role in socio-economic development, and in both countries female farmers outnumber men, and head around one third of households (Ardrey et al., 2006; Thomson and Baden, 1993). Equity and opportunity for women in agriculture is therefore critical to economic development. Increasing vegetable production would enhance nutritional status, generate income, and enhance access to learning and education, and the management capacities of farmers (Ali and Abedullah 2002). Most vegetable farmers are smallholders, that is, they farm areas typically of 0.05 – 0.3 ha and mostly only production that is surplus to subsistence requirements is sold commercially. Dry season (and late wet season) vegetable production presents challenges to farmers, while there is quite strong market demand for quality vegetables at this time. However, soil and water constraints limit dry season vegetable production, and improved management of these resources is required.

Soils used for vegetable production are often constrained by low fertility, poor structural stability and low water holding capacity and are difficult to manage sustainably. Many smallholder farmers are concerned about soil quality and the sustainability of cropping on their soils. Low fertility associated with acid conditions (e.g. phosphorus deficiency, aluminium toxicity, low cation exchange capacity, and structural instability) are characteristic of Acrisols, the dominant soils of Lao PDR and Cambodia (IUSS Working Group WRB, 2015). Low soil fertility also occurs on this and other soils in the valleys of the Mekong River and its tributaries (Blair and Blair, 2014; Seng et al., 2005). Soil analyses conducted on a limited number of sites in peri-urban Vientiane by Birch et al. (2014) also demonstrated low to moderate nutrient status. Upland soils (e.g. Ferrosols of the Bolaven Plateau, Champasak Province, Lao PDR) are inherently acidic, but of better initial fertility. However, Ferrosols are subject to rapid fertility decline and further acidification, with phosphorus and molybdenum deficiency symptoms observed in cultivated areas by Birch et al. (2014). An investigation into the potential to improve fertiliser, organic matter and lime management in vegetable crops on these soils was therefore warranted and was an objective (Objective 3) of this project.

Irrigation is necessary for vegetable production during the dry season because of the combined effects of low seasonal rainfall, low soil water holding capacity and high evapotranspiration. Also, the shallow root system of most vegetable crops limits their capacity to access water deeper in the soil profile. While vegetable farmers already irrigate in the dry season, the efficiency of irrigation is often low due to suboptimal use of technology (Bhattarai et al., 2011), and the lack of understanding of the relationships between soil water status, crop development and crop water needs, leading to inefficient timing and application of irrigation water. Another objective of this project (Objective 4) was therefore to examine methods for improving irrigation scheduling for key vegetable crops.

An ACIAR Scoping Study (Birch et al., 2014) of the vegetable supply chains in Lao PDR and Cambodia found evidence of failures in input supplies (e.g. appropriateness, availability, quality) and input supply chain functioning (e.g. timeliness of delivery, capacity to deliver, input product knowledge). Equally, there was limited evidence of understanding of requirements and how they might be delivered. They found that a thorough examination of input supply chains, their functioning and efficiency may lead to new approaches. An objective of this project (Objective 1) was therefore to identify opportunities to improve the functioning and performance of input supply chains in order to deliver inputs to farmers in a timely and efficient manner. Birch et al. (2014) also identified an investigation of socio-cultural and socio-economic factors as fundamentally important to the adoption of new technology and improved practices. Strategies for enhancing soil and water management in vegetable production systems need to be compatible with individual smallholder and community experiences, expectations, and capacities to meet capital costs. Using livelihoods and network analyses these socio-economic factors were also investigated by this project (Objective 2).

Improved management of soil and land resources and irrigation have been identified as keys to improved production and productivity by the Mekong River Commission (2011). Both Lao PDR and Cambodia also have policies favouring increased agricultural production as part of their economic development programs, and both seek improved production for import replacement, export availability and food security.

Lao PDR is making steady progress in reducing poverty, but remains one of the least developed countries in South-East Asia. Recognising the generally low productivity of agriculture and low competitiveness with regional neighbours Vietnam and Thailand (Leebouapao and Voladeth 2011), the Lao PDR Government policy objectives for agriculture include: (i) Achieving food self-sufficiency; (ii) Increasing agricultural exports through diversification, commercialisation and processing (cash crops, livestock, forest products); (iii) Irrigation development to increase rural incomes and stabilise food availability by expanding irrigated areas in both the wet and the dry seasons and improving operation and maintenance; (iv) Agriculture and forestry research: development of new technologies; and (v) Human resource development in agricultural-related fields (upgrading technical skills, and vocational training) (Panyakul, 2012).

These policies are fundamental to the detailed Lao PDR Strategy for Agricultural Development 2011-2020 (MAF, 2010), some of which is being implemented through the Clean Agriculture Development Centre (CADC). The Centre is charged with supporting conventional agriculture, and promoting good agricultural practice (GAP), pesticide-free agriculture and organic agriculture (Vitoon, 2009). Also, in response to the PROFIL project (Lao Organic 2004), Lao National Organic Agriculture Forum (UNCTAD, 2012) and perceived consumer preferences and market opportunities, the Ministry of Agriculture and Forestry intends to promote organic agriculture in two agro-ecological zones - The Mekong Corridor and The Bolaven Plateau.

Cambodia has made considerable progress in raising living standards but remains one of the poorest countries in South-East Asia. Agriculture is a significant part of the economy, and agricultural development offers the opportunity for economic advancement. The Cambodian Development Review in 2010 emphasised increased production, reduced poverty and enhanced economic development (Vuthy and Chhun, 2010). The Review recognises that agricultural productivity needs to increase to alleviate poverty in rural Cambodia, through meeting the requirements of the ASEAN Economic Community and ASEAN Good Agricultural Practice (GAP) policies and requirements (Nguyen and Bohme 2013).

Cambodia prefers to focus on productivity improvements in existing low input systems by adopting improved production technologies, and does not have a regulatory and standards framework for organic agriculture. However, Prak (2010) reported that there was a developing impetus to adopt organic agriculture principles and associated regulations. The Cambodian Association of Organic Agriculture (COrAA, 2013) provides two levels of certification (Organic and Chemical Free), using its own standards, but the penetration of organic agriculture appears to be low, as in Lao PDR.

Neither Lao PDR nor Cambodia mandates one form of agricultural production over another. The bulk of production is from conventional practices, ranging from traditional subsistence agriculture to highly intensive commercial enterprises. Given the generally low productivity of agriculture in both countries (ACIAR, 2013), with small holding sizes (summarised from various sources by Birch et al. 2014) and average vegetable yields of <9 t/ha, addressing fundamental drivers of production is essential. The emphasis of the project was on promoting good agricultural practice in whatever system farmers adopt that improve yield, enhance quality and contribute to agricultural, community and economic development.

The research strategy in this project was to provide capabilities for farmers to adopt and adapt new soil and irrigation scheduling technologies in their respective environments to support economic, social and development outcomes. A companion ACIAR project, ASEM/2012/081, addressed innovations in protected cropping and farm to market value chains to meet the challenges (Badgery-Parker et al., 2020). That project also built on the technical capacity developed in a previous ACIAR project, HORT/2006/107. This project (SMCN/2014/088) addressed soil and irrigation production constraints that were not considered in ASEM/2012/081. It also sought to understand the functioning of input supply chains and socio-cultural factors that either impede or facilitate adoption of improved practices. These aspects provided a platform for interventions to improve the performance of input supply chains and extension activities that enhance adoption of new technologies for improved soil and water management and thus improved production and economic outcomes.

4 Objectives

Objective 1:

To analyse input supply chains and identify opportunities to improve their functioning and performance to deliver inputs to farmers in a timely and efficient manner.

Note: The focus of the project was on input supply chains from manufacturers/importers to the farmers. A sister project (ASEM/2012/081) simultaneously studied the supply chain from the farm production downstream to the retail outlets.

Objective 2:

To analyse livelihoods and understand socio-economic and socio-cultural factors relevant to the adoption of improved soil and water management strategies and to design and implement strategies to improve adoption and associated household well-being.

Note: The focus of the project was on identification of smallholder farmer behaviour towards soil and irrigation innovations. After the Midterm review, the upscaling activities in Lao PDR were confined to two villages in Vientiane due to lack of resources.

Objective 3:

To develop technically sound and economically viable practices for management of structurally unstable and nutrient deficient alluvial soils (Acrisols) and upland soils (Ferrosols).

Note: The focus of the project was on testing and demonstrating improved NPK fertiliser, lime and organic matter management. Tillage management was removed from the project scope due to limited resources and feasibility.

Objective 4:

To develop improved management of irrigation in relation to soil-water status and crop requirements in various growth stages to improve crop yield and profitability.

Note: The focus of the project was on testing and demonstrating improved irrigation scheduling techniques using farmers' existing irrigation methods. Alternative irrigation technologies, such as drip irrigation, were not specifically targeted in this project as the focus, as detailed in the SRA report (SMCN/2014/015), was irrigation management (in relation to soil water status and crop requirements), as distinct from application technologies. The application and adoption of other technologies (e.g. drip irrigation) in vegetable production was addressed by others (e.g. HORT/2006/107). One irrigation scheduling trial was conducted in conjunction with ASEM/2012/081 at Siem Reap early in the project. While the trial featured drip technology, the focus of the work was irrigation scheduling.

5 Methodology

5.1 Research locations

Cambodia is situated along and west of the lower Mekong River and has a tropical savannah (seasonally dry) climate. It receives 1500 – 2000 mm average annual rainfall. Lao PDR is mostly mountainous and spans latitudes 14 – 23^{o} N. The north of the country has a humid subtropical climate, while the south has a climate similar to that of Cambodia, but with some areas receiving >2000 mm average annual rainfall (adapted from Janssen 2008).

Two provinces in Cambodia (Kampot and Siem Reap) and two in Lao PDR (Vientiane, and Champasak) were chosen for socio-economic and field research. The provinces were chosen because they are important vegetable production regions and also had soil and water constraints to production. The southern provinces of Lao PDR produce well over 50% of the national production of leafy vegetables, with Champasak Province being by far the largest producer (Ministry of Planning and Investment, 2019). Champasak province is also a leading producer of root, leguminous and other vegetables. Further, in the context of this project, it offered two very different production environments in close proximity, being the Ferrosol soils of the Bolaven Plateau and the floodplains of the Mekong near Pakse. Vientiane and Vientiane Capital provinces are also significant producers of leafy, leguminous and other vegetables. Siem Reap and Kampot Provinces are not large producers of vegetables in the Cambodian context, however, they were chosen as suitable locations for the work of this project on the basis of access to collaborators (e.g. PDA staff), international flight logistics for Australian staff and future potential production from smallholder enterprises. Work in Kampot was a challenge because Kampot is the province in Cambodia with the shortest dry season and most farmers use rice fields for vegetable cropping. The soils in these fields are poorly structured and drained (Blair and Blair, 2014). Average rainfall events (>10 mm) often led to waterlogged conditions at project trial sites that damaged or destroyed crops. Unreliable weather patterns in Siem Reap province also negatively affected field trial work.

After visits to candidate villages and on-farm sites within each province, discussions and scoring against selection criteria, potential sites for field experiments, field demonstrations and village socio-economic analysis were shortlisted. The selection considerations are listed in the Appendix (Section 11.1). After the second season, field sites for replicated experiments were moved to research farms available to partner staff because of the high risk nature of on-farm research. Commercial farms are inappropriate locations for replicated scientific research as farmer production priorities will always take precedence over the requirements of scientific rigour. This was considered to be an even greater barrier to rigour than might normally be the case given that Australian partners could only visit field sites a few times a year and there was an additional language constraint in achieving understanding and agreement of the need to follow scientific protocols within commercial operations. There was also a reluctance from researchers to take new ideas and concepts they were not familiar with out to farmer sites. Demonstration sites remained on smallholder farms and varied from year to year depending on availability and interest of the farmer in collaborating and farming operations planned for that year. The villages involved in the socio-economic, experimental and demonstration field research are shown in Table 1 and their general locations shown in Figure 1.

Table 1. Province and village locations of project socio-economic research and for experimental and demonstration field sites in Lao PDR and Cambodia

Country	Province	Socio-economic		Experimental		Demonstration	
		Village	**Lat/Lon**	**Village**	**Lat/Lon**	**Village**	**Lat/Lon**
Lao PDR	Vientiane Capital	Pakxapkao ບ້ານ ປາກຊາບເກົ່າ	18°08’24” N 102°46’31” E	National University of Laos, Nabong Campus ມະຫາວິທະຍາໄລແຫ່ງຊາດ, ວິທະຍາເຂດນາບົງ	18°07’28” N 102°47’31” E	Pakxapkao ບ້ານ ປາກຊາບເກົ່າ	18°08’24” N 102°46’31” E
		Huaha ບ້ານ ຫົວຫ້າ	17°51’02” N 102°36’24” E	Hokkaido Horticultural Research Centre, Huaha ສູນຄົ້ນຄ້ວາເມັດພັນຫາດດອກແກ້ວ, ບ້ານ ຫົວຫ້າ	17°51’36” N 102°35’50” E	Huaha ບ້ານ ຫົວຫ້າ	17°051’2” N 102°36’24” E
	Champasak	Thongset ບ້ານ ທົ່ງເສັດ	15°12’24” N 106°17’57” E	Thongset ບ້ານ ທົ່ງເສັດ	15°12’24” N 106°17’57” E	Donley ບ້ານ ດອນໄລ່	15°06’39” N 105°46’13” E
		Katouad ບ້ານ ກະຕວດ		Lao-Viet Agricultural Research Station, Nonghin ສະຖານີຄົ້ນຄ້ວາກະສິກຳລາວ-ຫວຽດ, ໜອງຫີນ	15°11’05” N 106°15’06” E	Nongbua ບ້ານ ໜອງບົວ	15°06’11” N 105°45’58” E
				35 km Agricultural Research Station for Southern Lao, Paksong ສະຖານີຄົ້ນຄ້ວາກະສິກຳພາກໃຕ້ຫຼັກ 35, ເມືອງ ປາກຊ່ອງ	15°10’25” N 106°05’52” E		
Cambodia	Siem Reap	Popis ពពិស	13°21’58” N 103°47’02” E	Popis ពពិស	13°21’58” N 103°47’02” E	Popis ពពិស	13°21’58” N 103°47’02” E
		Ta Trav តាត្រាវ	13°20’07” N 104°01’44” E	Tuek Vil Experiment Station ស្ថានីយពិសោធន៍**ទឹកវិល**	13°24’11” N 103°47’36” E	Ta Trav តាត្រាវ	13°20’07” N 104°01’44” E
	Kampot	Koun Sat កូនសត្វ	10°35’48” N 104°16’42” E	Koun Sat កូនសត្វ	10°35’48” N 104°16’42” E	Trapeang Chrey ត្រពាំងជ្រៃ	10°52’04” N 104°26’56” E
		Trapeang Chrey ត្រពាំងជ្រៃ	10°52’04” N 104°26’56” E				
		Prey Ben ព្រៃបែន	10°48’49” N 104°28’22” E				
	Phnom Penh			CARDI	11°28’39” N		

Country	Province	Socio-economic		Experimental		Demonstration	
				ກາຊີ	104°48’28” E		

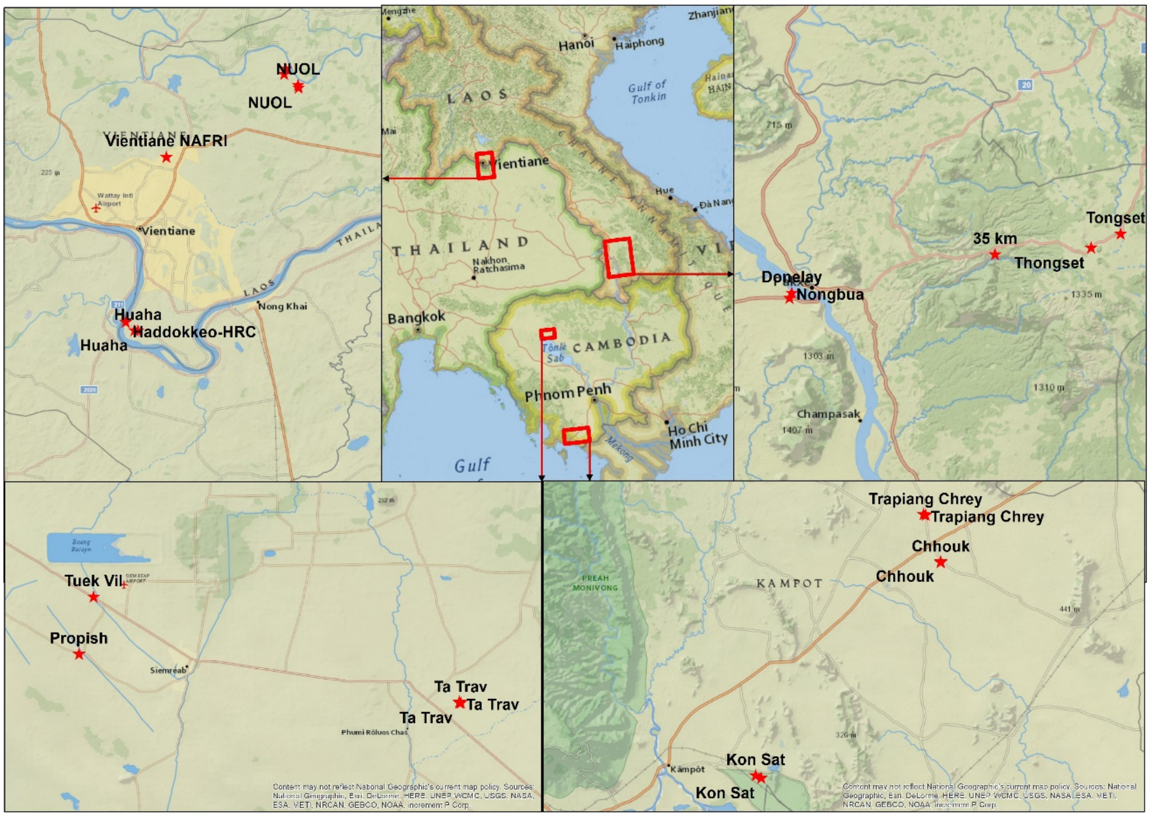


Figure 1. Country overview (top centre) of locations of project villages across Vientiane Capital (top left) and Champasak Provinces (top right) in Lao PDR, and across Siem Reap (bottom left) and Kampot Provinces (bottom right) in Cambodia. Map created by Jochen Eberhard, USQ, April 2018.

5.2 Capacity and capacity building

5.2.1 Project team capacity

The Australian team consisted of: Dr Alice Melland who took on leadership in January 2016 after Associate Professor Colin Birch sadly passed away, Mr Erik Schmidt (USQ) who provided mentorship and also led the project from April 2017-April 2018 while Dr Melland was on maternity leave, Dr Stephen Ives (UTas) who was co-leader of the project, Dr Ann Starasts (USQ) who led Objectives 1 & 2 for Cambodia, Assoc. Prof. Laurie Bonney (UTas) who led Objective 1 in Lao PDR, Dr Gomathy Palaniappan (UQ) who led Objective 2 for Lao PDR. Dr Jochen Eberhard (USQ) who joined the team in 2017 and became Objective 3 leader, Dr Jasim Uddin (USQ) who led Objective 4 until leaving the project in April 2018, Mr John McPhee (UTas) who worked across Objective 3 and 4 became Objective 4 leader in May 2018, and Dr Suzie Jones (UTas) who joined the team in 2017 to support the soils and irrigation objectives.

The Cambodia component of work was initially led by Dr Vang Seng and then from February 2019 by Dr Sarith Hin, both from the Soil and Water Section of CARDI. Mr Lim Vanndy, Mr Veasna Touch and initially Mr Ly Tyneth also contributed to Objectives 3 & 4. From the socio-economic section of CARDI, Dr Chea Sareth led, Mr Ratana Tech co-ordinated, and Ms Yin Putheavy contributed to Objective 1 & 2 research in Cambodia. PDA staff from Kampot and Siem Reap provinces also contributed.

The Lao PDR component was led by Dr Bounneuang Douangboupa and co-ordinated by Mr Phaytoune Mounsena from NAFRI HRC. Mrs Vilayphone Tounglien (HRC) contributed to Objective 3 & 4 research. The NUoL project leader was Assoc. Prof. Fongsamouth

Southammavong, and Ms Mayer Xiong co-ordinated the NUoL team and the Lao PDR Objective 1 & 2 research. Ms Sisouvanh Phimasonne and Assoc Prof Somphou Inthong contributed to Objectives 3 & 4. CADC had a small funded component in the project, led by Mr Bouthsakone Inthalangsee after Dr Thongsavath Chanthasombath sadly passed away in early 2016. Provincial Agriculture and Forestry Office (PAFO) staff from Champasak province also contributed.

5.2.2 Capacity building

Capacity of research, development and extension agencies in Lao PDR and Cambodia to undertake resource (land, soil, water) related research, socio–economic studies and supply chain assessment was built through collaborative implementation of the project, data collection and analysis, planning and implementation workshops, mentoring of project participants, and training of staff in both countries. Further details are in Section 7.5.1.

Training by way of small group workshops and field application was undertaken in value chain management and analysis, livelihoods analysis, qualitative interviewing, focus group methods, experimental design, and soil and irrigation assessment methods immediately prior to the field research teams commencing their research. In addition, one on one discussions through the project with individual researchers and with participating stakeholders occurred in relation to research and extension methods.

The project adopted a problem-centred learning approach to training in value chain analysis using a mix of short theory sessions, collaborative development of survey and input value chain mapping tools and then pre-testing of those tools in the field and the collaborative planning of the field research.

5.3 Input supply/value chain analysis

This project, SMCN/2014/088, analysed vegetable input supply chains from manufacturers/importers to the farmers (Figure 2). A companion project, ASEM/2012/081 - Improving market engagement, postharvest management and productivity of the Cambodian and Lao PDR vegetable industries, addressed the supply chain from the farm production downstream to the retail outlets.

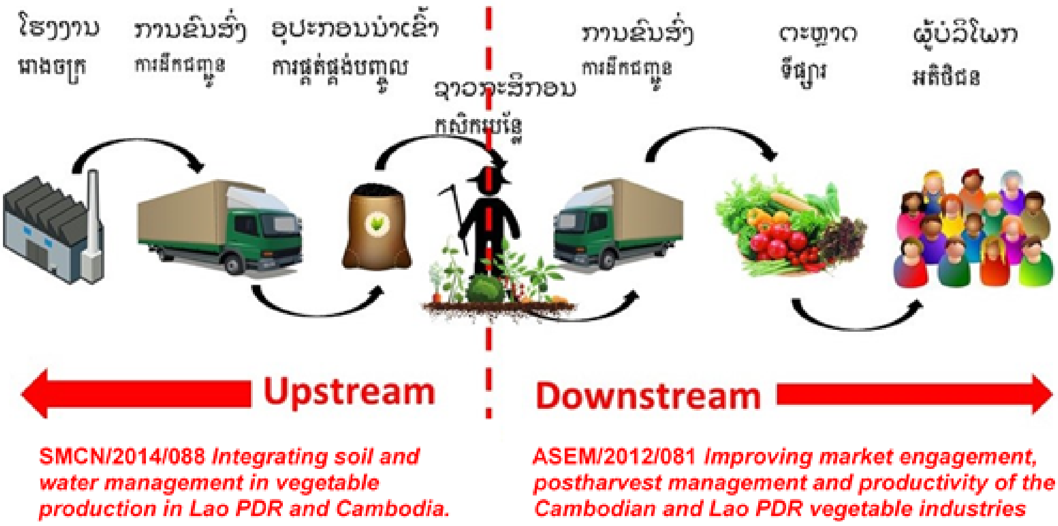


Figure 2. The focus of two ACIAR projects along the upstream and downstream value chains for vegetable farmers in Lao PDR and Cambodia

In Lao PDR and Cambodia, the overall approach for input supply/value chain analysis adopted was Participatory Action Research using mixed qualitative and quantitative methods to collect input supply chain data. An emphasis on structured interviews and quantitative survey was necessitated due to inexperience with semi-structured qualitative techniques.

In **Lao PDR** a structured survey to understand input resource usage was almost equally divided between Vientiane and Champasak in the villages of Pakxapkao (19%), Nasala, Huaha (25%), Thongset (29%) and Katouad (26%). Of those interviewed 71% were male and 29% women. The learnings from the economic survey (105 participants) included the difficulty in obtaining consistent data with such a complex structured questionnaire across all interviewees. This informed the approach for the Rapid Value Chain Analysis (RVCA)(Collins and Dunne, 2008) due to the amount of time taken and the complexity of the surveys and a second round of interviews being undertaken in which the sample size was reduced by half (52 participants) and the scope of the interview questions was reduced. This involved approximately equal random samples of farmers from the same two villages in each of the Vientiane and Champasak districts. Interviews were conducted with the manufacturers or importers of input supplies tracing them to their source. The data were then analysed using simple descriptive statistical analysis and qualitative thematic analysis. As a follow on exercise to identify the geographic movement and constraints in the animal manure input supply chain to the horticultural industry in the Paksong District of Champasak Province in Southern Laos, the team employed the 'Convergent Interviewing' form of semi-structured interviewing. Convergent interviewing converges on commonly held views, identifies, investigates and records divergent views (Riege & Nair, 2004) until data saturation is achieved. Reflective practice was also employed to highlight emergent learnings (Pakman, 2000) leading to Thematic Analysis of interview notes from three small group interviews and seven individual interviews as well as documents provided by PAFO and NAFRI (Boyatzis,1998).

In **Cambodia** analysis initially consisted of a Farming Systems structured survey of 120 farmers from 5 villages, through which data were collected about input products (including manure), purchase, pricing and information sources associated with vegetable production. Following this a series of structured interviews was undertaken with input suppliers in both provinces:

Kampot Province – Structured interviews were conducted with 11 suppliers from Chhouk market including 4 seed-suppliers, 3 fertilizer-suppliers, 2 pesticide-suppliers, and 2 equipment irrigation systems-suppliers. Suppliers in Rorng market in Koun Sat village, Koun Sat commune, and Tuk Chhour district declined to be interviewed.

Siem Reap Province – Structured interviews were held with 5 suppliers from Ang Krong Pouk and Krabey Real markets. Suppliers from some villages chose not to participate, limiting the number of participating suppliers in the study.

The input supplier interviews covered demographics about suppliers and their roles in problem solving in vegetable production, and supply sources of seed, fertilizer, pesticides, irrigation equipment and information. Focus group discussions with farmers during 2018 and 2019 highlighted issues in relation to access to lime products which then prompted additional small studies in lime availability.

5.4 Livelihoods analysis

In **Lao PDR**, household sample surveys were used to analyse livelihoods and access to resources in the selected community sites. The advantage of household survey was that it allowed the flexibility of data collection instrument to accommodate a larger number of questions on the 5 capitals (Groves et al., 2011). The limitations of cost and time involved in conducting surveys was managed through purposive sampling and trained enumerators for data collection. The survey instrument was constructed, pre-tested and modified by both Australian and Lao research teams. The training of enumerators, who were students from the National University of Laos, for field data collection took place during 2016 at

Vientiane by the research staff and team leaders. Purposive sampling was conducted to gain representative samples through judgement, by including participants based on selection criteria. The researcher relied on his/her own judgement to select sample group members that match the selection criteria. This method is less time consuming as suitable candidates are targeted compared to many other sampling methods. Results of purposive sampling are usually more representative of target population compared to other sampling methods. The selection criteria for sampling comprised the following: i) vegetable grower, ii) willingness to participate in the interview and iii) willingness to participate in project activities.

In **Cambodia**, thirty vegetable producers were surveyed from each village (two-three villages per province). A sample of 30 vegetable producers from each village was selected using purposive sampling on the basis of stratified income, to ensure that a representative sample of the range of existing socio-economic conditions was included. A structured series of open and closed questions was developed participatively with the project team regarding households, income, resources, capital, networks, farm and soil and irrigation strategies. The survey collected quantitative (demographic) and qualitative (social) data about the households, their current strategies and their potential for change. Focus group discussions occurred at the start of the project in each of the five Cambodian villages (Total 65 participants [39 female]; Trapeng Chhrey 10 [6 female], Prey Ben 15 [8 female], Koun Sat 12 [4 female], Ta Trav 13 [9 female], Popis 15 [12 female]) to discuss soil and water management in terms of current activities and potential for change.

5.5 Extension

Extension strategies commenced with initial village discussions and individual interviews as part of the Livelihoods analysis which included discussions about problems and information needs and sources as well as data collection about labour, profitability, farm inputs. Following the establishment of demonstration sites in villages, field days were held during the vegetable growing seasons of 2018, 2019 and 2020 along with annual discussions about participants learning and adoption issues. Extension strategies were initially planned at the PIPA workshop and then refined in line with Livelihoods research findings, field day farmer discussions, and discussed and refined at each annual meeting. They included the provision of technical information and the identification of future roles for vegetable production stakeholders.

Activities aimed to be inclusive by supporting local populations to develop and own their own solutions, and to ensure that each individual farming family had ongoing access to technical information and experts, and opportunities to ask questions and see and evaluate vegetable management options. Extension strategies (Figure 3) in this project were developed to assist participants (farmers, PDA, input suppliers) and stakeholders build knowledge, change beliefs and enhance skills and to work towards making plans to adopt new soil and irrigation strategies (Figure 4). Such strategies build on learning and resourcing of villagers.

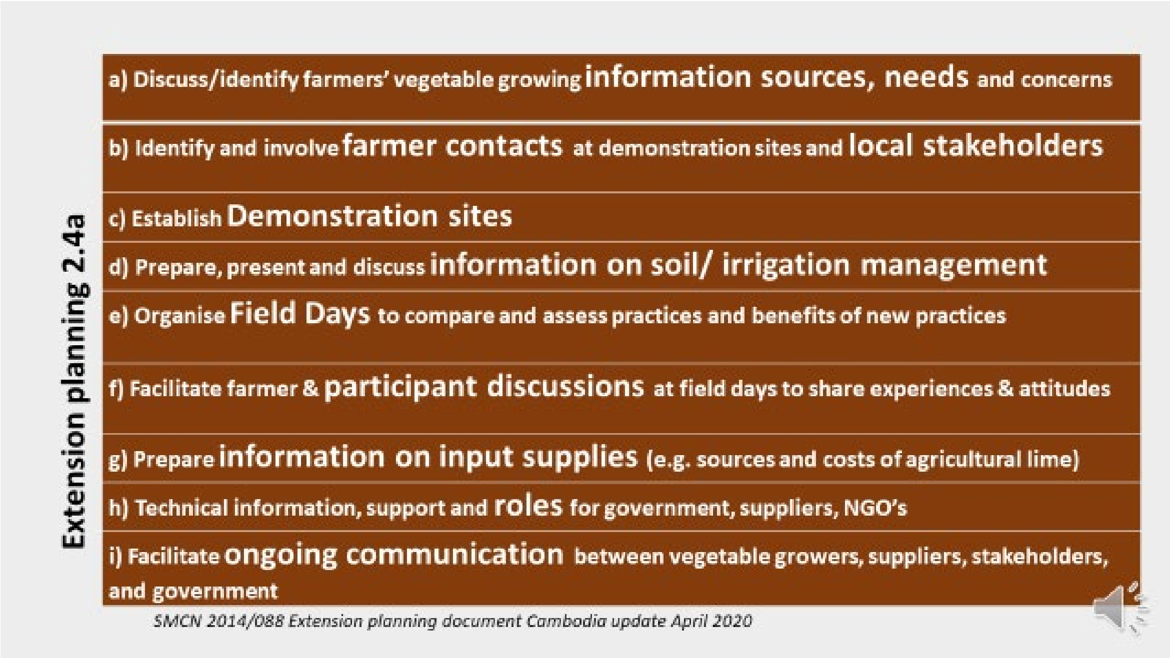
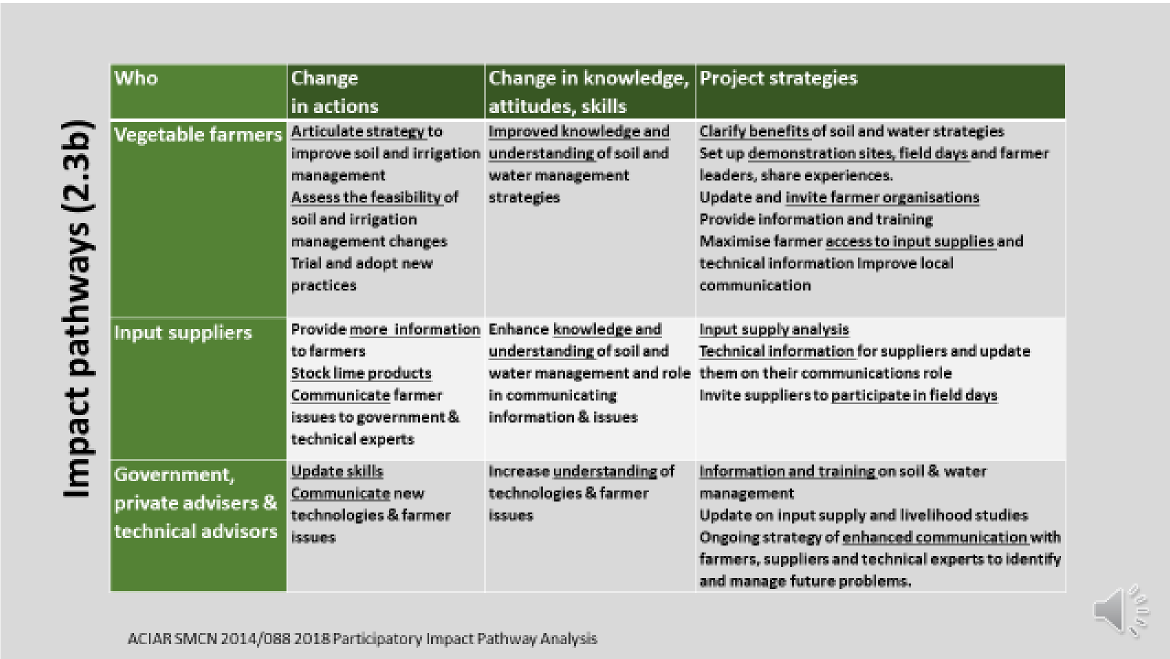


Figure 3. Summary of extension planning strategies



Who	Change in actions	Change in knowledge, attitudes, skills	Project strategies
Vegetable farmers	Articulate strategy to improve soil and irrigation management Assess the feasibility of soil and irrigation management changes Trial and adopt new practices	Improved knowledge and understanding of soil and water management strategies	Clarify benefits of soil and water strategies Set up demonstration sites, field days and farmer leaders, share experiences. Update and invite farmer organisations Provide information and training Maximise farmer access to input supplies and technical information Improve local communication
Input suppliers	Provide more information to farmers Stock lime products Communicate farmer issues to government & technical experts	Enhance knowledge and understanding of soil and water management and role in communicating information & issues	Input supply analysis Technical information for suppliers and update them on their communications role Invite suppliers to participate in field days
Government, private advisers & technical advisors	Update skills Communicate new technologies & farmer issues	Increase understanding of technologies & farmer issues	Information and training on soil & water management Update on input supply and livelihood studies Ongoing strategy of enhanced communication with farmers, suppliers and technical experts to identify and manage future problems.

Figure 4. Project extension strategies and impact pathways (Starasts, 2019 PIPA Report)

5.6 Field trials

Field trials were conducted to develop technically sound and economically viable practices for management of structurally unstable and nutrient deficient alluvial soils (Acrisols) and upland Ferrosols, and to develop improved management of irrigation in relation to soil-water status and crop requirements in various growth stages. The soil management treatments studied were a) balanced and appropriate NPK fertiliser rates, b) different rates of lime application and c) different types and rates of organic matter. The irrigation management treatments included different rates and timing of irrigation.

Three dry seasons were studied: 2016-2017 (1st season), 2017-2018 (2nd season), 2018-2019 (3rd season) and there was insufficient budget for a fourth season of field work to occur (in the dry season of 2019-2020). Field trials were undertaken as either replicated experimental treatment sites, or unreplicated demonstration sites. The distribution of trials and treatments across seasons are described in the Appendix (Section 11.4). For the first round of replicated trials in the dry season 2016/17 the team in Lao, PDR, selected five sites in Vientiane province and three sites in Champasak province. In Cambodia, two sites in Siem Reap province and two sites in Kampot province were earmarked for replicated trials. For the second dry season 2017/2018 the Lao, PDR, team put a focus on using government research stations to facilitate better controlled replicated trials while farmer sites were used for demonstrations. In Cambodia, a similar approach led to engaging a larger number of farmers in hosting demonstration sites in both provinces. One replicated trial was established at research facilities in Siem Reap province, which later failed due to heavy flooding. The dry season 2018/19 was mainly a replication of the trials and demonstrations from the previous year with six sites in Vientiane province in Lao, PDR, and six locations in Champasak province. However, early rain there caused the replicated trials at research stations to fail. In Cambodia, there were six sites in Siem Reap province and six sites in Kampot province. Some sites had a follow-on crop. A replicated trial at the CARDI research facilities failed.

In Lao PDR, the team set up all the trials as replicated experiments for the first two seasons. This required a huge effort in setting up and data collection. It was recommended to have at least three replications, and most of the experiments had four replications. In the last season 2018/19, the team made the distinction between replicated experiments and demonstration sites. The replicated sites were either at the NAFRI Horticulture Research Centre or the NUOL research station. In contrast, all farmer sites had unreplicated demonstrations. The team in Cambodia was more focused on unreplicated demonstrations after the first season, with the intention to reach more farmers and increase the impact of the project.

Several demonstrations and replicated experiments failed or didn’t go ahead every season due to delayed release of operating funds, early onset of rain season and poor crop management of farmer (primarily lack of weed control). Internal reporting requirements, particularly in Lao PDR, also made it difficult to plan and respond in a timely manner for the next season. The timing of visits was always a compromise. Ideally there should have been a planning session every July-August (in the middle of the monsoon season) to allow partners enough time to work through their department administration requirements. Visits by Australian partners did not usually occur at that time because trips were normally planned to allow the opportunity to also visit active field sites.

The teams in both countries quickly concentrated their efforts on leafy vegetables and broccoli, as this crops allowed a one-off harvest which was easier to manage particularly for CARDI in Cambodia.

The layout of the replicated experiments usually was in randomised block design while the demonstrations used one bed per treatment. The size of the bed was similar to what the farmer operated with and measured on average about 20 m in length and around 1.6 m in width.

Seedling production was not part of this project, so it was up to farmers in most cases to produce and supply the planting material for the trials and demonstrations. The common farmer practice is to establish a seedling bed where the seed is applied at high density. When the majority of seedlings are about right for transplanting, they are extracted (dug up) and planted by hand into the growing beds. Because of the high density in the seedling bed, the separation process causes a lot of root damage which makes it hard for the seedlings to establish themselves after transplanting. While farmers aim to use the biggest plants from the seedling bed, the heterogeneity in plant development can be significant, which can have an impact on transplant establishment and homogeneity of the crop later on. Leftover plants in the seedling bed are being used to replant when transplants don't establish appropriately within the first week. The replicated trials conducted at research facilities in Lao PDR had seedlings produced in greenhouses in seedling trays.

Crop development was captured by recording plant height, plant width and, depending on the type of crop, leaf numbers on a weekly or fortnightly basis. At harvest, the plant density, individual plant weight and yield per m^2 was measured. In lettuce, sometimes the total and marketable yield was recorded.

If data from the replicated experiments was of sufficient quality, statistical analysis was conducted with SAS v9.3 or R.

6 Achievements against activities and outputs/milestones

6.1 Objective 1: To analyse input supply chains and identify opportunities to improve their functioning and performance to deliver inputs to farmers in a timely and efficient manner

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.1	Value Chain analysis training for key project personnel (A)	Built capacity of key personnel and operational staff involved in data collection (Training attendance, Action Plan, Trip Report)	December 2016 (December 2016)	A program was developed by Associate Professor Laurie Bonney. Training was delivered in Cambodia (by Dr Stephen Ives) to 6 staff from CARDI Socio Economic team. Discussions identified between Value Chain (products) and Input Supply Chain (inputs) and participants became familiar with the concepts of quality and price, incentives, collaboration and innovation in creating value, with an increase in overall value of the product with all participants in the chain sharing. Discussions on research planning occurred and extensive in-field training occurred in interviewing and focus group discussions as data collection methods. Understanding the vegetable farming community, collaborative development and field testing of farming systems survey questions occurred in-field with 17 farmers from two villages (including 8 women). Initially in Laos 19 people received basic awareness training about value chains followed by subsequent training, using problem-centred learning techniques, for a core group of 11 project field researchers in interviewing and focus group interviewing. The training included the co-design of the surveys and planning for field data collection.
1.2	**Document, analyse and evaluate the functioning, performance and effectiveness of input supply chains**			

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.2a	Undertake a Rapid Value Chain Analysis (RVCA) of the key input supply chains for project areas in Vientiane, Champasak, Siem Reap and Kampot (PC, A)	Identification of existing constraints and opportunities for improvement of input supply and value chains. (Two focus group discussions conducted per location, RVCA Report in Annual Report)	August 2018 (August 2018)	The analysis focussed on input supply chain for fertiliser, seed and irrigation equipment. Cambodia: Interviews with 11 supply businesses in Kampot (Choukk district) and 5 suppliers in Ang Krong, Pouk and Krabey Real markets in Siem Reap explored products, sources, labels, information and other issues. A farming systems survey of 120 farmers from 5 villages explored farm inputs, rates, prices, information access. Focus group discussions at farmer field days further explored and identified issues related to the input supply chain including information needs and availability of lime products. Lao PDR: Input supply chain surveys were completed in 4 villages in Lao PDR (2 in Vientiane, one is Pakxapkao Village Xaythany Districty and one is Huaha village, Hadxaifong district, then 2 other villages are in Paksong district, Champasak province). The survey consisted of 60 samples per village for input supply. A structured economic value chain survey was conducted with 105 respondents almost equally divided between Vientiane and Champasak in the villages of Pakxapkao (19%), Nasala, Huaha (25%), Thongset (29%) and Katouad (26%). Of those interviewed 71% were male and 29% women. The learnings from the economic survey (105 participants) included the difficulty in obtaining consistent data with such a complex structured questionnaire across all interviewees. This resulted in major modifications to the approach for the Rapid Value Chain Analysis (RVCA) due to the amount of time taken and the complexity of the surveys and a second round of interviews being undertaken in which the sample size was reduced by half (52 participants) and the scope of the interview questions was reduced. This involved approximately equal random samples of farmers were selected from two villages in each of the Vientiane and Champasak districts. <u>Outputs</u> Tech, R. (2018) Initial summary of Interviews with Input Suppliers ACIAR SMCN 2014/088 Project Report. Starasts, A. et al. (2020) Vegetable Input Supply Chain Analysis-Cambodia. Technical Report Bonney, L.B. et al (2020) ACIAR SMCN 2014 088 Objective 1 Lao PDR Final Report. University of Tasmania (including supply chain maps) Xiong, M, et al. (2019) 'Do GAP Practices Improve Market Access for Vegetable Farmers? A Case Study from Vientiane Capital, Laos', Proceedings, vol. 36, no. 1, p. 78. Xiong, M. et al. (2019) 'Integrating soil and water management in vegetable production in Lao PDR and Cambodia: input supply chain case study in Lao PDR', poster presented to NAFRI Vegetable Forum, Vientiane.
1.3	**Quantify the capacity and efficiency of existing input supply chains**			

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.3a	Map sources and potential sources of soil ameliorants (including manures) and irrigation inputs (PC, A)	Determination of sources and potential sources of soil amendments (organic), conventional fertilisers and irrigation components (Supply Chain Maps)	September 2018 (September 2018)	Cambodia: Fertiliser and seed products were mainly sourced from Thai-based companies, but also Vietnam and China companies. Animal manures are widely used and available in local villages. Irrigation inputs were available mostly only at a small number of specialised stores with very limited sources of information about irrigation. Lime availability is a problem, with only builders' lime available and sources are too far away from farms. Wholesale companies provided information on agronomy and products to suppliers, but not all suppliers provided information to farmers. Lao PDR: The upstream input supply chain is quite opaque and that appears to be due both to business confidentiality and the main suppliers being in external countries. There is no manufacturer of inputs in Laos, except white lime. Laos has reserves of rock phosphate and the Laos Government should consider ways of obtaining Foreign Direct Investment to enable the exploitation of those reserves. The movement of cattle and chicken manure is largely within and between neighbouring provinces and does not cross-national boundaries. Demand is growing rapidly with Foreign Direct Investment in horticulture in the Paksong District. The analysis shows that Lao PDR is not optimising the planned value from the Strategy for agricultural development 2011 to 2020 and a number of recommendations are made to improve domestic adoption and value capture. <u>Outputs</u> Tech, R. (2018) Initial summary of Interviews with Input Suppliers ACIAR SMCN 2014/088 Project Report; Starasts, A. et al. (2020) Vegetable Input Supply Chain Analysis-Cambodia. Technical Report Bonney, L.B. et al (2020) ACIAR SMCN 2014 088 Objective 1 Lao PDR Final Report. University of Tasmania (including supply chain maps)

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.3b New	Identification of the constraints on inputs, and capacity to supply in terms of quality and volume (PC, A)	Identification of the constraints on inputs, and capacity to supply in terms of quality and volume using snowball sampling and other techniques (Trip Report)	August 2019 (August 2019)	Cambodia: Constraints to the supply chain were identified and include limited information on product rates, application methods, safety and handling and withholding periods in the local language for some imported products. There was little availability of locally adapted seed varieties and suppliers had difficulty storing seeds. Farmer late payments for products influenced suppliers' ability to make payments to companies and threatened their ability to operate. Potential strategies for improvement include using microfinance for inputs, and improved information and training for both suppliers and farmers. Farmers do not know how to apply lime. Farmer issues identified were high cost of inputs, increasing information needs, limited communication and for some, limited education which may influence abilities to read product labels and safely manage products. Lao PDR: A lack of price incentive and the effort, time cost as well as the skills, knowledge and resources required to attain and maintain the Good Agriculture Practice (GAP) and the Organic Agriculture (OA) mitigates against small horticultural producers adopting the standard. It appears that the supply of animal manure is a constraining factor to the Organic Agriculture Policy. Farmers' skill levels are low and they require regular short course training in all aspects of production and marketing of vegetables. <u>Outputs</u> Starasts, A. et al. (2020) Vegetable Input Supply Chain Analysis-Cambodia. Technical Report Tech, R. CARDI Initial summary of interviews with input suppliers. ACIAR SMCN 2014/088 Bonney., L. et al. (2019) Trip 15 Organic manure snowball sampling, Lao PDR, June 2019, University of Tasmania, NUoL Bonney, L.B. et al. (2020) ACIAR SMCN 2014 088 Objective 1 Lao PDR Final Report. University of Tasmania (including supply chain maps)
1.4	**Recommend institutional changes to improve input supplies to horticulture**			

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.4a New	Recommend institutional changes to improve input supplies to horticulture (PC, A)	Prepare Input Supply Chain Improvement Policy Recommendations Report (Report)	September 2019 (September 2019)	Key recommendations developed for each country (see Key Results and Discussion). Cambodia: Recommendations developed for the government Ministry of Agriculture, Forestry and Fisheries, the Provincial Departments of Agriculture, wholesale and local input suppliers, NGOs, other research projects and vegetable sellers. Recommendations include that PDAs ensure that input suppliers supplying vegetable farmers are aware of appropriate fit-for-purpose lime, fertilisers and pesticides for use in vegetable production and that all products have labels in Khmer language including appropriate application, safety and withholding information. Wholesalers should provide information on their products in Khmer language which input suppliers should then make available to farmers. Registration of importing companies and suppliers would enable communications about products and product tracing. Lao PDR: Recommendations for institutions include registration schemes for agricultural suppliers and animal manure traders be introduced and monitored, a requirement be introduced that all imported input supplies have labels in the Lao language attached as a condition of import approval and that extension materials and short course training be provided for farmers. <u>Outputs</u> Bonney, L.B. et al. (2020) ACIAR SMCN 2014 088 Objective 1 Lao PDR Final Report. University of Tasmania, which includes supply chain maps. Starasts, A. et al. (2020) Vegetable Input Supply Chain Analysis-Cambodia. Technical Report

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
1.6	Disseminate research outcomes through regular workshops, printed and electronic media, conferences and journal publications (PC, A)	Success stories scaled up through dissemination avenues (Publications Conference presentations Media-based information)	i. December 2019 (December 2019) ii. March 2020 (in progress)	Poster presented at TropAg2019 and abstract published. Papers submitted or in preparation as per outputs listed below on input supply chains and implications for institutional change in Lao PDR and Cambodia. Cambodia - Letters to supply shops, companies, NGOs, PDA and Government outlining recommendations and their potential future role in upscaling, scaling out and project legacy were drafted and sent to CARDI staff. Outputs Bonney, L. et al. (In Preparation) Constraints to adoption of 'organic' and 'GAP' standards by smallholder vegetable farmers in Lao PDR. Starasts, A. et al. (2019) Investigating Capacities to Change Soil and Irrigation Practices in Vegetable Production in Two Provinces in Cambodia. Proceedings 2019, 36, 210 Starasts, A. et al. (In Preparation) Input supply chain constraints and opportunities for smallholder vegetable farming in Lao PDR and Cambodia. Xiong, M., et al. (Submitted) Organic Manure Supply and Standards Constraints in Paksong District of Champasak Province in Southern Laos. National Agriculture and Forestry Research Institute Journal. (Lao) Xiong, M. et al. (Submitted) Methodology for Value Chain and Livelihoods Analysis. Journal of Agricultural Science, Technology and Development, JASTD. (Lao) Xiong, M. et al. (Submitted) Inputs Supply Chain Analysis for Vegetable production in Vientiane Capital and Champasak Province, Lao PDR. Journal of Agricultural Science, Technology and Development (Lao)

PC = partner country, A = Australia

6.2 Objective 2: To analyse livelihoods and understand socio-economic and socio-cultural factors relevant to the adoption of improved soil and water management strategies and to design and implement strategies to improve adoption and associated household well-being

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.1	Training workshop in appreciative inquiry and participatory approaches for undertaking surveys/ analysis (A)	Built capacity of key project personnel in preparation for undertaking surveys and analysis Livelihoods analysis planning and training workshop (Training attendance, Trip Report)	December 2016 (December 2016)	November 2016, Dr Palaniappan in Lao trained 19 participants (two of whom were socio-economic researchers and the remainder were biophysical researchers) on participatory methods (resource mapping); qualitative methods (Focus Group Discussion, semi-structured interviews) and quantitative methods (Survey) of data collection using livelihood framework. Discussions identified between livelihood capitals (Physical, Financial, Social, Natural and Human capitals) and smallholder farmer behaviour (adoption or rejection) and participants became familiar with the concepts of farmers' access to capitals, utilising capitals and entry points for change of practice. Discussions on research planning occurred and extensive in-field training occurred in interviewing, focus group discussions and participatory research mapping as data collection methods. Lao PDR: Developed and tested interview guide for household interviews, topic guide for focus group discussions and guide for participatory resource mapping. Cambodia: In December 2016, training in Livelihoods frameworks and qualitative research occurred including interviewing and focus group discussions led by Dr Starasts. Participants were six socio-economic researchers from CARDI. Extensive in-field training in qualitative research (interviewing and focus group discussions) and testing survey instruments in two villages in Kampot Province. Team planning, team building and research planning for undertaking the Livelihoods analysis occurred.

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.2	Finalise Livelihoods analysis research protocol, and initial participatory impact pathway analysis (PC, A)	Documentation of Livelihoods analysis research protocol Participatory impact pathway discussions & initial documentation (Livelihoods Analysis Plan & initial PIPA notes in Annual Report)	March 2016 (March 2016)	Livelihoods analysis plans finalised. Planning, workshop and documentation finalised (Dec 2016). In Lao PDR, the household survey was planned in selected intervention sites Pakxapkao (Xaithany district, Vientiane Capital), Huaha (Hadxaifong district, Vientiane Capital), Thongset (Paksong district, Champasak province) and Katouad (Paksong district, Champasak province). The survey consisted of 25 to 30 respondents per village and a total of 114 respondents was completed with Huaha (27 households), Katouad (31 households), Pakxapkao (25 households) and Thongset (31 households). In Cambodia, the livelihoods survey consisted of 120 respondents across 5 vegetable-growing villages across varying socio-economic conditions, including Koun Sat (29 households), Trapeang Chhrey (14), Prey Ben (18), Ta Trav (29), Popis (30). The survey collected data on households, income, resources, capital, networks, farm and soil and irrigation strategies. The survey and initial focus group discussions collected quantitative (demographic) and qualitative (social) data about the households, their current strategies and their potential for change. Participatory Impact and Pathways Analysis (PIPA) completed and initial document completed. The PIPA report was updated throughout the project as new data became available. Also see 2.3b. <u>Output</u> Starasts, A. (2019) Participatory Impact Pathways Analysis ACIAR SMCN 2014 088 March 2019. Report
2.3	**Livelihoods, and socio economic and socio-cultural analysis related to adoption of soil and water management practices**			

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.3a	Undertake Livelihoods analysis of vegetable producing household members and socio economic and socio cultural analysis related to adoption in Vientiane, Champasak, Siem Reap and Kampot (PC, A)	Completion of surveys and analysis Identification and documentation of resources, constraints, processes and strategies and potential outcomes related to Livelihoods Analysis (Livelihoods Report)	i.April 2018 (April 2018) ii. August 2018 (August 2018)	Livelihoods analysis and reports completed. Findings identify low levels of education and a strong reliance for some on cash flow associated with vegetable production. Poor or no returns plagued approximately one third of farmers. In Cambodia, most farmers sourced information largely from within their family or village and some household members did not often communicate beyond their family networks. Similarly, in Lao PDR most farmers relied on personal experience and informal networks (family, friends, and colleagues) to meet their information needs. Many farmers had attended training and varying percentages were prepared to trial and adopt new technologies (ranging from 4% of women in one village in Laos to over 50 % of participants in another village in Cambodia). The studies identified different roles for female farmers including sowing, weeding and post-harvest activities whilst males undertook land preparation and pest and disease management especially in Lao PDR. However, across all sites in Lao PDR, traditional task division is gradually changing, and women are increasingly involved in land preparation and irrigation. The results indicated that both men and women farmers have decision making power on the soil and irrigation management practices to manage their land. Soil preparation methods are commonly trialled by farmers in Pakxapkao and irrigation practices trialled in Thongset as part of our project and as part of private sector (e.g. fertiliser company) trials. Farmers during livelihood surveys stated that they have been trialling as private sectors approached them and reject if it didn't work for them. In Cambodia many men left the farm to obtain outside employment, leaving females to often manage some aspects of vegetable production. Most farmers used their own money to fund vegetable inputs. Usually two family members worked the farm. Most farmers used their own money to fund vegetable inputs, but farmers indicated high input costs and that most profits were used in family living expenses. Very few farmers in Cambodia accessed microfinance to pay for farming inputs. Some families in Laos accessed microfinance to pay for family consumption. In Lao PDR vegetable collectors practised informal lending during harvest, in return for the farmers' produce. Informal lending and borrowing are commonly used by farmers for various reasons including sharing of risk, long-term relationships and trust. <u>Outputs</u> Starasts, A. and Tech, R. (2020) Livelihoods and Farming Systems – Cambodia. Technical Report Palaniappan, G. et al. (2018) Baseline Livelihood Analysis -Lao PDR. Technical Report

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.3b	Impact pathway analysis from implications of Livelihoods and other analyses for integrating soil and water management in vegetable production (PC, A)	Map potential livelihood strategies and impact pathways (including constraints to adoption) for farmers, government and private sector participants, input suppliers, and specifically female participants with respect to the adoption new soil and water management practices. (PIPA Report)	June 2017 Revisit April 2018 and April 2019 (April 2019)	The PIPA report was updated after the MTR and a Monitoring, Evaluation and Learning framework completed. Most recent update March 2019.The analysis identified that key problem areas were farmer confidence and knowledge and the availability of information along with poor management of fertiliser and pest and disease strategies. It identified low availability of water for some in dry times. The analysis highlights target audiences as farmers, suppliers and government and agribusinesses. Many male farmers cannot attend field days or training as they are working off farm. This is also limiting the availability of labour on farm and impacts on farmers' abilities to make changes to vegetable production. Further planning is necessary. It identifies experimentation, demonstrations, sharing, education and information provision, improved communications, training and the establishment of networks as key strategies. Farmers' education levels and small networks may limit their ability to understand extension and training information, making field-based events important. <u>Outputs</u> Starasts, A. (2019) Participatory Impact Pathways Analysis ACIAR SMCN 2014 088 March 2019. Report Ives, S. and Jones, S. (2019) SMCN_2014_088 MEL Framework. Update 20190320. Working document.

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.3c	Village farmer group planning discussions	Discussion and confirmation of relevant Livelihoods and adoption issues. (Summary Report of farmer group discussion issues)	Sep 2019 (September 2019)	Cambodia: Village field day discussions held now with ten farmer groups across 8 villages over 2 years. Discussions have identified that many male farmers work off farm, which may limit the availability of labour on farm and time for learning new things. Farmers are requesting information on how to grow vegetables, how much and how to apply fertilisers including lime, and information about sources of lime, and on pest management. They are seeking to produce quality vegetables safely and many highlighted the high cost of agricultural inputs and the large rates of inorganic fertiliser used. Villagers identified their concerns as increasing acidity in their soils (30-40% participants), the high rates of fertiliser being used in vegetable production and the high costs associated with this and their needs for a more healthy and sustainable system with efficient irrigation practices. This analysis is guiding extension planning. Lao PDR: At an irrigation training day, farmers discussed the strategies practised to improve water retention of soil by applying manure, rice husk, straw to cover the soil, and one farmer (from the south) mentioned using black plastic to cover the soil. Farmers in Pakxapkao also used green nets to cover their garden. Village discussions were held in 4 villages with male and female participants. Farmers expressed need for information on soil fertility and irrigation through radio and televisions. Farmers agreed that they will make changes if it worked well for their neighbours; will adopt practices if the technique has trialability, productive and better market price. Farmers expressed lack of incentives for safe vegetable production despite increase in cost for inputs and trainings to follow GAP practices. Also, lack of availability of organic inputs was reported by farmers. The information from farmer discussions guided tracking organic input supply chain and extension planning. <u>Outputs</u> Tech, R. (2018) Summary report farmer adaptation new agricultural technology. Technical Report. Xiong, M. et al. (2018) Soil characteristics and water for Lao farmers. Report Palaniappan, G. et al. (2018) Identifying the drivers for adoption of innovation. Report
2.4	**Extension plan**			
2.4a	Develop a plan and recommendation to enhance adoption of improved and sustainable soil and water management practices (PC, A)	Documentation, circulation and refinement of an extension plan including stakeholders and participating networks. (Extension Plan and Recommendations report)	December 2019 (December 2019)	Extension plans were developed in line with findings from Livelihoods analysis, PIPA and village discussions. Post MTR discussions with partners along with feedback from the MTR led to the development and agreement of action plans for 2019, which included further extension planning, targeted training, and networking activities. Extension activities include establishing demonstration sites, field days, information products, and a network of support for the vegetable industry. <u>Outputs</u> Bonney, L. et al. (2018) Lao Objective 1 2 Plan of Action for 2019. Working document. Starasts, A. et al. (2019) Cambodia Objective 1 2 Plan of Action for 2019. Working document. Starasts, A. and Tech, R. (2020) Extension for soil and water management in vegetable production in Kampot and Siem Reap Provinces SMCN 2014/088. Report Starasts, A. (2018, 2020) Extension planning document Cambodia ACIAR SMCN 2014/088 Working document

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.5	**Delivery of extension activities**			

2.5	Develop and deliver targeted extension activities, tools, information products for smallholders, including specifically female participants, private sector providers, input suppliers, and regional extension officers (PC, A)	Activities and materials developed for target vegetable production audiences and advisors. Delivery of at least 6 events or products per year (Annual Report)	iii. May 2020 (partially completed- impacted by COVID-19)	Farmer notes for lime, fertiliser and irrigation recommendations were developed and prepared in English, Khmer and Lao. Further training material was developed for irrigation management (see Activity 4.6) and was handed out to 37 field day participants in February 2020 in Lao PDR. Farmer notes were distributed and explained to 245 farmers in Cambodia in 13 villages, to 15 suppliers and to 35 PDA staff. Videos were not produced in Cambodia due to restrictions and time limitations, however farmer note information will be posted on the Extension Department website. Videos on lime and irrigation management for farmers were prepared in Lao for lime, fertiliser guidelines and irrigation guideline adoption. Field days: Cambodia: A total of 17 field days and 13 Farmer Note training events to demonstrate lime application, fertiliser recommendation rates and irrigation strategies were held across two provinces attracting 744 attendees through the project, including farmers (729), NGOs, company representatives, input suppliers and other project staff. Lao PDR : A total of 9 field days and training events to demonstrate lime application, fertiliser recommendation rates, irrigation methods, pest and disease management and chemical use requirements were held across two provinces attracting 171 attendees through the project, including farmers (118), NGOs, company representatives, input suppliers, project researchers and government extension staff. In Cambodia draft letters to stakeholders are prepared outlining key extension messages. Project 1 on 1 discussions with supply shops held to provide technical information; Government collected and shared information about lime sources to supply shops, farmers & stakeholders; Some shops are supplying ag lime and report increased demand for lime products. Value Chain network analysis in Nasala village, Lao PDR with 8 farmers (4 male and 4 female farmers) and Pakxapkao with 10 farmers (5 males and 5 female farmers) identified traders to be the most important actor followed by organic manure supplier, retail shopkeepers and neighbours. Traders sold produce in the market, organic supplier provided organic manure and shopkeepers recommend fertilisers. Assessment of gender roles in Nasala, village, Lao PDR with 8 farmers (4 male and 4 female farmers) and Pakxapkao with 10 farmers (5 males and 5 female farmers) identified that women make decisions on growing crops, management and selling. Women's self-esteem is increased as the farmer group is being recognised by the village and district authorities for following GAP practices. Participation in vegetable forum in Vientiane allowed NGOs; PAFO and DAFO; small enterprise; and seed companies to be identified as dissemination pathways. Decision support tools: Research technical aids for irrigation research and extension were developed. As part of an ACIAR-funded SALM Cross-project, a Lime requirement calculator app was developed. Outputs **Extension materials- Farmer Notes, Factsheets and Technical Notes** ACIAR SMCN 2014 088 (2018a) Applying lime in vegetables. Factsheet, Cambodia ACIAR SMCN 2014 088 (2018b) Irrigating vegetables. Factsheet, Cambodia ACIAR SMCN 2014 088 (2020a) Vegetable growing-fertiliser, lime and irrigation Farmer Note Cambodia ACIAR SMCN 2014 088 (2020b) Vegetable growing-fertiliser, lime and irrigation Farmer Note Lao PDR (Lao, English) ACIAR SMCN 2014 088 (2020c) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Technical Note (Khmer, English)

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments **Note: Outputs are in English language unless otherwise stated in parentheses**
				ACIAR SMCN 2014 088 (2020d) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Technical Note (Lao, English) ACIAR SMCN 2014 088 (2020i) Irrigating vegetables. Farmer Note Cambodia (English, Khmer) ACIAR SMCN 2014 088 (2020j) Lime and fertilizer application for leafy vegetables on sandy acid soils (Prey Khmer and Prateah Lang soil groups). Farmer Note. (Khmer) ACIAR SMCN 2014 088 (2020k) Irrigation management for short, medium and long leafy vegetable crops in Siem Reap and Kampot provinces. Farmer Note (Khmer) **Extension materials - Videos and decision support tools** ACIAR SMCN 2014 088 (2020e) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Training presentation (Khmer, English- narrated) ACIAR SMCN 2014 088 (2020f) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Training presentation (Lao, English - narrated) Sisouvanh, P. & Xiong, M. (2020) Irrigation, fertiliser and lime application extension videos (Lao) https://www.youtube.com/watch?v=2kfl4ycuXZw&t=260s https://www.youtube.com/watch?v=Agez_ubnyRw&t=31s https://www.youtube.com/watch?v=bJvNV-7FPN4&t=60s ACIAR SMCN 2014 088 (2020g) Lime calculator. Android App. (Khmer, English, Lao) ACIAR SMCN 2014 088 (2018c) Distribution Uniformity-Infiltration Calculator - MS Excel Technical Aid ACIAR SMCN 2014 088 (2018d) ETc Irrigation Calculator - MS Excel Technical Aid **Reports** Palaniappan, G. and Xiong, M. (2019) Value chain network analysis (Report) Palaniappan, G. et al. (2019) Gender roles in vegetable production (Report)
		Assessment of acceptance of extension plans and resources and revision where necessary on the basis of feedback and new R&D data (Interim reports in Annual Report)	ii. March 2020 (March 2020)	Cambodia: Cambodian partners agreed and supported the Cambodia Objective 1 and 2 Plan of Action for 2019. Farmer feedback highlighted their needs for more detailed technical information on fertilisers, lime application and sources (and pest management). Information and strategies to facilitate information access for farmers was incorporated into extension resourcing. Specific training needs on more complex irrigation management strategies were highlighted by staff and led to training outlined in 4.6. Lao PDR: Meetings held with Department of Extension and Ministry of Agriculture and Forestry guided the team to identify and conduct the following activities. 1. Contributed to the development of training for input suppliers planned by the Ministry of Agriculture and Fisheries by providing information on safety management, storage and transport of inputs. (Feb 2020, 1 workshop in Vientiane, 1 workshop in Champasak) 2. Contribute to further improve the existing handbook on vegetable growing by providing findings on the soil management and irrigation scheduling.
2.6	**Evaluation, publication and upscaling**			

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.6a	Evaluation of effectiveness of extension activities (A)	Evaluation of extension activities in terms of KAP indicators and in terms of Livelihood Analysis indicators: Interim evaluation Project Evaluation (Interim Farmer Adaptation Report, and Final Evaluation Report	i. Interim September 2019 (September 2019) ii. June 2020 (partially completed-impacted by COVID-19)	Partially completed. Lao PDR: An evaluation of pest and disease training in Lao PDR was conducted with 38 participants in October 2018. The majority of the participants found the training to improve their knowledge on harmful and beneficial insects. Evaluation of farmer adoption of project findings was impacted by COVID-19 restrictions. Cambodia: Discussions with farmer groups at field days provided some feedback on the initial extension approach. Attendees at field days were mostly female as many male farmers were working off farm. Approximately 47-64% believed that applying lime in vegetables can increase yields. Twelve to 23% of respondents wanted to test lime in their vegetable crops. A 2020 assessment indicated that farmer interest in lime across both provinces ranged from 90 to almost 100% of participating male (12) and female (23) farmers. Adoption of lime in vegetables has doubled through the life of the project in Siem Reap (now 61%) and increased seven-fold in Kampot province (now 49%). Outputs As per 2.3c Xiong, M. et al. (2018) Pest and Disease Management Training Report, Technical Report, NUoL, PPC Tech, R. et al. (2020) SMCN2014/088 Objective 2 Cambodia. Presentation for Final Review
2.6b	Collect and publish data on extension methods and technology adoption in journals and conferences (PC, A)	Research findings disseminated (Publications and Conference attendance Trip Reports)	i. November 2019 (November 2019) ii. March 2020 (May 2020)	Two posters presented at TropAg 2019 and abstracts published. Two papers submitted for publication in Lao language journals. Other papers in preparation as per below. Outputs Palaniappan, G. et al. (In Preparation) Livelihoods analysis reveals opportunities to influence practice adoption and change in smallholder vegetable farmers in Lao PDR and Cambodia Starasts, A. et al. (In Preparation) Input supply chain constraints and opportunities for smallholder vegetable farming in Lao PDR and Cambodia. Starasts, A. et al. (2019) Investigating Capacities to Change Soil and Irrigation Practices in Vegetable Production in Two Provinces in Cambodia. Proceedings 2019, 36, 210 Xiong, M. et al. (2019) Do GAP Practices Improve Market Access for Vegetable Farmers? A Case Study from Vientiane Capital, Laos. Proceedings 2019, 36, 78. Xiong, M. et al. (Submitted) Methodology for Value Chain and Livelihoods Analysis. Journal of Agricultural Science, Technology and Development, JASTD. (Lao) Xiong, M. et al. (Submitted) Livelihoods analysis of vegetable producing household members and socio-economic and socio-cultural analysis related to adoption in Vientiane and Champasak. National University of Laos Journal (Lao)

No.	Activity	Outputs/ Milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
2.6c	Upscaling and development of ongoing resources and network to support a legacy for the project for a broader community audience. (PC, A)	Development of resources, identification of key local contacts and networks, along with information and training where necessary to ensure ongoing project outcomes (Project resources, Local networks, Report in Final Report)	May 2020 (May 2020)	Partially completed. In Cambodia, meetings with NGOs and local projects involved in vegetable production extension have indicated their willingness to demonstrate and educate farmers from other villages in relation to lime in vegetable production. These stakeholders were invited to village field days and one person from Agricultural Development Denmark Asia (ADDA), 4 commercial company representatives, and 4 people from the markets attended a 2018 field day in Ta Trav village. Technical information was delivered and explained to 245 farmers including to 8 villages beyond the project villages. Letters to stakeholders including suppliers, other projects, and NGOs, distributed with technical information and inviting them to help demonstrate and educate farmers from other villages. COVID restrictions limited opportunities to produce extension videos in Cambodia. Meetings with the Ministry of Agriculture and Forestry were held in Lao PDR guiding scale out activities through public extension.

PC = partner country, A = Australia

6.3 Objective 3: To develop technically sound and economically viable practices for management of structurally unstable and nutrient deficient alluvial soils (Acrisols) and upland soils (Ferrosols) To develop improved management of irrigation in relation to soil-water status and crop requirements in various growth stages to improve crop yield and profitability.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
3.1	Conduct training workshop in field experiment design, implementation and management including data quality control. (A)	Built capacity within research partners and operational staff (Training attendance and evaluation, Trip Report)	October 2016 (June 2016)	Three training and planning workshops were conducted by Australian staff (2 USQ, 1 UTAS) in Lao PDR (HRC, Vientiane - 14 June 2016; Pakse, Champasak - 17 June 2016) and Cambodia (CARDI - 21 June 2016) on Experimental Design and Implementation covering aspects such as principles of experimental design, site characterization, record keeping, health and safety, and project-specific experimental layouts and treatment. A total of 30 (6 women and 24 men) project and non-project staff from the partner countries attended across all workshops. An impromptu training session on field experimentation (experimental design, data recording, interpretation etc.) was held for Pakse staff at the Agricultural Research Station for Southern Lao, km 35, Paksong on 25 Nov 2017. Local staff feedback on the training workshops was generally positive. One-on-one mentoring was delivered for the preparation of the MS PowerPoint presentations for the annual meeting in 2017. Ongoing encouragement for the research teams to follow standard procedures for data collection, interpretation and reporting occurred throughout the project.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
3.2a	Undertake soil sampling, soil analysis, field site selection (PC, A)	i. Sites selected ii. Soils characterised iii. Soils data used to support decisions on operational directions in Activities 3.2b and 3.3 (soil amendment and fertiliser requirements) (Site selections in Annual Report, Experimental Designs in Annual Report)	i. October 2016 (October 2016) ii. February 2017 (February 2017) iii. February 2017 (February 2017)	i. Farms short-listed, visited and assessed against selection criteria. Recommendations made for experimental and demonstration sites and for allocation of particular experimental foci to each site. ii. Soil samples from all replicated and demonstration sites were analysed for pH, EC, macronutrients, CEC and soil texture at two soil depths (0-15cm, 15-30cm). iii. Most sites had the expected low soil pH of <5.5 with all Cambodian soil returning very acidic conditions while some of the soils around Vientiane and the highland in Champasak in Lao PDR had reasonable pH levels. Almost all soils had moderate to high phosphorus levels. Only the soils at the research stations in Lao PDR had moderate to high potassium levels while all farm soils in both countries had low or very low plant available potassium. Organic matter in some of the soils of intensive vegetable farms in Lao PDR was well above average, probably due to regular incorporation of rice husk and animal manure, while particularly the soils in Kampot province in Cambodia, which are also used for rice growing, had low to very low levels of organic matter.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments **Note: Outputs are in English language unless otherwise stated in parentheses**
3.2b	Establish replicated experimental field trials involving a range of soil ameliorants, nutrient sources and field layouts across a succession of seasons (PC, A)	Treatments applied Crops established Data on site responsiveness to inputs (Annual Reports)	i. March 2017 (1st season) (March 2017) ii. December 2017 (2nd season) (March 2018) iii. December 2018 (3rd season) (April 2019) iv.December 2019 (4th season) (Not completed)	i. Season 1 2016-17. Replicated experimental field trials have been established in Vientiane (1) and Paksong (1) in Lao PDR, and Siem Reap (1) and Kampot (1) in Cambodia. One planned site in Vientiane didn't eventuate as the farmer was in a hurry to establish the crop and experimental organisation couldn't be completed in time. ii. Season 2 2017-18. Lao PDR: 1 site at NUOL research farm in Vientiane, (lettuce, irrigation x fertiliser/lime focus). 2 sites at HRC fields (lettuce and spring onion, organic matter x lime, irrigation based on ET soil moisture balance). 2 sites at research farms in Champasak province (broccoli, 1 with irrigation and 1 with compost x lime, irrigation at both sites based on ET soil moisture balance). 1 site at a private farm (broccoli, lime) was established well after the rain season started. Cambodia partially complete. No replicated site in Kampot province because of insufficient support from local government department and suitable farmers. In Seam Reap province the establishment of the site at Tuek Vil research station (Chinese Kale, irrigation x lime) was delayed for various reasons and later abandoned due to flooding and high temperatures. iii. Season 3 2018-19. Lao PDR Champasak province: At the research station km 35 broccoli was planted early April to measure the effect of higher (recommended) potassium rates and sulphur (4 treatments). Vientiane province: 2 replicated trials at HRC to measure the performance of 4 different organic materials/fertilisers to assist farmers in deciding where to source their organic soil amendments. Spring onions and lettuce were planted mid March but part of the lettuce trial was flooded early on due to malfunction of an irrigation channel. The trial was to be replanted in April. In Huaha village 2 sites were planted with bok choy and coriander, respectively, to measure different rates of organic fertilisers and cultivation practices. Cambodia Not completed. No replicated trials were established to maximise the number of sites to demonstrate yield improvement by applying lime with the limited human resources available. iv. Season 4 2019-20. No field sites were established due to insufficient budget to cater for the extra project year.

3.2c	Monitor and report on replicated trials	Data on crop yield and quality collected and analysed Preliminary extension messages developed	i. July 2017 (1st season) (July 2017) ii. July 2018 (2nd season) (July 2018) iii. July 2019 (3rd season) (July 2019) iv. May 2020 (4th season) (Not completed)	i. 1st season. Lao PDR: NUOL prepared a report for the replicated and demonstration sites in Xaithany District under their control in 2016/17 (Sisouvanh et al. 2017). While higher rates of organic fertiliser in the replicated trials improved yields, the effect wasn't large enough to base an extension message on it. Farmers also reported increased plant health issues, suggesting that new application methods need to be introduced at the same time. HRC prepared reports for the replicated and demonstration sites in Hadxaifong District under their control in 2016/17 (Vilayphone et al. 2017). Different rates of N and optimum P and K didn't affect the total yield of pak choy compared to farmer application rates. Soil was fairly high in pH but low in K. No information has been forthcoming on how much NPK actually was applied. The farmer used Urea at a rate of 140 kg N/ha per crop, and applied no P or K. Data from the Champasak experimental site and demonstration sites (2) was presented at the annual meeting 2017 (McPhee et al. 2017). All work in this season was affect by administrative and funding delays. Data collection and documentation was poor as a result. Misinterpretation of experimental protocols resulted in some of the treatments being identical. If interpretation of the data is correct, none of the treatments improved yield for lettuce, tomatoes and morning glory compared to farmer practice. Cambodia: There were extremely limited crop responses to variations of NPK and organic fertiliser application rates suggesting low soil pH was the primary limitation for improving yields (Touch et al. 2017, Hin et al. 2017). In fact, "farmer practice" fertiliser application frequently exceeds, often dramatically, well documented nutrient requirements for vegetables across both countries. ii. 2nd season. Lao PDR: The replicated experiment at NUoL for lime and irrigation treatments was successful and good quality data were produced. Differences between treatments were not significant but highlighted excessive rates of nitrogen as farmer practice (Sisouvanh et al. 2018) Two of the three experiments in Champasak were rained out due to late internal approval of the budgets. The third one showed an effect of different fertiliser use and potential sulphur deficiency which was explored in the 3rd season (Vilavong et al. 2018). Cambodia: no data from the one replicated experiment as it was planted late and needed to be abandoned after some heavy rainfall. iii. 3rd season Lao PDR: A number of replicated experiments were conducted with organic fertilisers at HRC and on commercial farms nearby. The effect of different rates of organic fertiliser were evaluated for a number of crops (lettuce, spring onions) as well as a repeat of the trial from the previous season comparing different types of organic fertilisers. One replicated trial used different rates of NPK (15:15:15). Some of the results with organic fertilisers rates were highly variable due to flooding of part of the trial site at one stage, others showed limited improvement of yield with higher application rates. The different types of organic fertilisers also had limited effect on the yield of coriander, which is not unexpected, as they all consisted of organic materials that were processed to some degree. Different NPK rates had some effect on yield but only in the low treatment. Other limitations might have been in place, like high residual fertiliser loads in soil, soil pH, which wasn't measured because it was not a lime trial. (Vilayphone 2019) Champasak province had no replicated sites this season Cambodia: the focus was on demonstration sites only with only one replicated site for an irrigation trial.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
				iv. Season 4 2019-20. No field sites were established due to budget limitations. <u>Outputs</u> Touch, V. et al. (2017) Cambodia annual meeting Objective 3 & 4 Result Summary Kampot.pdf Hin, S. et al. (2017) Cambodia annual meeting Objective 3&4 Result Summary Siem Riep.pdf McPhee, J. et al. (2017) Lao PDR SMCN-2014-088 Champasak Province Replicated Experiment Report 2017 Sisouvanh, P. et al. (2017) Lao PDR SMCN-2014-088 Xaithany District Experiment Report 2017.pdf Sisouvanh, P. et al. (2018) Lao PDR SMCN-2014-088 Replicated Experiment Report. NUoL 2018. Vilayphone, T. et al. (2017) Lao PDR SMCN-2014-088 Hadxaifong District Experiment Report 2017 Vilavong, S. et al. (2018) Replicated experiments of the impact of nutrient and lime treatments on broccoli growth and yield in Champasak Province, 35 km station 2017-18, Lao PDR, Replicated Experiment Report. Vilayphone, T. (2019) Lao PDR SMCN-2014-088 Hadxaifong District Experiment Report 2019

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
3.3a	Establish demonstration trials involving a range of soil ameliorants, nutrient sources and field layouts (PC, A)	Data on site responsiveness to inputs Basis of extension messages (Annual Reports)	i. March 2017 (1st season) (March 2017) ii. December 2017 (2nd season) (March 2018) iii. December 2018 (3rd season) (April 2019) iv. December 2019 (4th season) (Not completed)	i. In season 1 (2016/17) in Lao PDR, three demonstration sites were successfully established in Vientiane province and data on crop growth, yield and irrigation were collected. In Paksong two out of four demonstration sites were established with yield and irrigation data being collected. Two other potential sites were not established due to insufficient water to last to the end of the dry season in one case, and lack of easily accessible water in the other. In Cambodia the one demonstration site in Kampot province failed to establish due to unseasonally early rain. The demonstration site in Siem Reap province with lime treatments was successful and was used to provide direction for the following season as the yield improvements due to lime suggested low soil pH as primary limiting factor for improving soil fertility. ii. In season 2 in Lao PDR, one demonstration site in each province (Vientiane - lettuce and Champasak - broccoli) was established. Lime was applied to raise the pH of the soil by 0.5 units on the basis of a soil analysis. In Cambodia, season 1 results suggested low soil pH as the primary limitation to improving yields and CARDI decided to significantly expand the number of demonstration sites in season 2, and to focus on lime applications to promote the findings. Despite multiple setbacks because of unseasonal frequent rain, Kampot province produced 8 crops (Chinese cabbage, mustard green, cucumber) on 6 demonstration sites, though with variable data quality. Siem Reap sites produced 8 crops (bok choy) on 4 sites demonstrating mostly the positive short and long-term effect of lime on yield of leafy vegetables. Application rates for lime were 25%, 50% and 100% of liming requirements to raise soil pH to 6.5. The results of the first round of demonstrations had already been used as extension material for field days held during the second round of crops at the same sites (also on project website in local language). Some of the demo sites were cropped twice without a second application of lime to demonstrate the requirement for a continuous liming regime. iii. In season 3 Lao PDR: Champasak province; In Paksong one site was planted with broccoli to demonstrate the effect of optimised NPK (rate and ratio) and lime compared to “farmer practice” (total 4 treatments). Sites at Donley and Nongbua along the river near Pakse were planted with lettuce and morning glory. The treatments were a comparison between “farmer practice” and recommended/optimised NPK rates to motivate for reduced fertiliser usage. Vientiane: 2 sites in Pakxapkao demonstrated the effect of applying NPK at recommended rates and small quantities of lime on plant development and yield of lettuce. Cambodia: 12 sites total. Kampot Province: Response of mustard green to lime rates, 3 sites. Response of mustard green to NPK fertiliser and lime application, 3 sites. Siem Reap Province: Response of bok choy to lime rates, 3 sites. Response of bok choy to NPK fertiliser and lime, 3 sites. iv. Season 4 2019-20. Not completed. No field sites were established due to budget limitations.

3.3b	Maintain demonstration trials	Data on crop yield and quality collected (Annual Reports)	i. July 2017 (1st season) (July 2017) ii. July 2018 (2nd season) (July 2018) iii. July 2019 (3rd season) (July 2019) iv. May 2020 (4th season) (Not completed)	i. Season 1 Lao PDR: Trends in the data suggested a low response to variable NPK rates and combined with the information from the Cambodian sites, it was concluded that low soil pH was most likely the main limiting factor across most of the sites in both countries and that the main focus for the season 2017/18 should be on demonstrating the requirement for actively managing the pH of the soil. (Details see McPhee et al. (2017), Vilayphone et al. (2017) and Sisouvanh et al. (2017). Cambodia: data collected from the one demonstration site in Siem Reap in 2016/17 showed vast improvements in yield due to high applications of lime to raise soil pH to around 6.5 (80 – 90% increase of Bok Choy yield). Although this is a result from an unreplicated site it was the only one that provided a clear direction for the season 2017/18 (Hin et al. 2017). ii. Season 2. Lao PDR: Data were collected on plant density and height, number of leaves, marketable yield and groundcover. Results showed that liming in itself doesn't provide a large positive effect on yields on heavier soils with a pH of above 5 (Sisouvanh, 2018). It was unclear if this was due to the type of lime (dolomite) being used which, for administrative reasons could only be applied very close to the date of transplanting. Cambodia: Data were collected and used to inform field days as per 3.3a (Hin et al. 2018). iii. Season 3. Lao PDR: Champasak province; data collected from two of the sites (one crop failed) and reported, including a basic cost-benefit analysis. All demonstrations showed similar trends, with higher yields and larger profit margins if more suitable NPK fertilisers, particularly with higher potassium content, were used. 3 sites were established in Vientiane province to demonstrate the effect of lime application and crop specific NPK application rates on yield of lettuce. On sites with low farmer yields, the improvements were larger with any of the treatments than when farmer yield was already high. The combined effect of the treatments always had the highest yield. In Champasak province liming was not demonstrated as most soils have a suitable pH for vegetable production. Vientiane: 2 sites in Pakxapkao demonstrated the effect of applying NPK at recommended rates and small quantities of lime on plant development and yield of lettuce (Mounsena, 2019). Cambodia: 12 sites total. Kampot Province: Response of mustard green to lime rates, 3 sites. Response of mustard green to NPK fertiliser and lime application, 3 sites. Siem Reap Province: Response of bok choy to lime rates, 3 sites. Response of bok choy to NPK fertiliser and lime, 3 sites. Results suggest that a combination of better NPK ratios and lime improves the yield of vegetables compared to "farmer practice" in Cambodia (Hin and Touch, 2019). iv. Season 4 2019-20. No field sites were established due to budget limitations. <u>Outputs</u> Hin, S. et al. (2017) Cambodia annual meeting Objective 3 & 4 Result Summary Siem Riep Hin, S. et al. (2018) ACIAR SMCN 2014 088 CARDI Demonstration Site Report July 2018 Hin, S. and Touch, V. (2019) ACIAR SMCN 2014 088 CARDI Demonstration Site Report July 2019 Mounsena, P. (2019) Partner Progress Report NAFRI 18 July 2019. Report. Sisouvanh, P. et al. (2017) Lao PDR SMCN-2014-088 Xaithany District Experiment Report 2017 Sisouvanh, P. (2018) On Farm Demonstration, Pakxapkao, Vientiane, Lao PDR, 2017-2018, Technical Report

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
				McPhee, J. et al. (2017) Lao PDR SMCN-2014-088 Champasak Province Replicated Experiment Report 2017 Vilayphone, T. et al. (2017) Lao PDR SMCN-2014-088 Hadxaifong District Experiment Report 2017
3.4	Conduct training for local Government, business and other service staff in new and innovative technology and practice (PC, A)	Improved capacity of extension staff (Training attendance and evaluation, Trip Report)	i. December 2016 (December 2016) ii. May 2019 (May 2018) iii. May 2020 (February 2020)	i. see activity 4.5 ii. see activity 4.5 iii. Informal training on experimental design; data collection and interpretation, lime and fertiliser applications; and data collection was provided to 3 provincial agricultural staff. ACIAR Murdoch University cross project in Cambodia facilitated three field days to which local government and extension services staff attended.
3.5	Develop simple technical support guidelines for soil management inputs (PC, A)	Support tools for extension staff developed Improved capacity for extension (Soil input management guidelines in extension format)	September 2019 (May 2020)	An ACIAR Murdoch University cross-project facilitated development of a lime application calculator app for smartphones in Cambodia (Eberhard, 2020). Key lime and fertiliser management recommendations were developed as extension messages for farmers. The messages were developed into Khmer and Lao Farmer Notes. Videos explaining the key lime and fertiliser messages have been produced in Lao for Lao vegetable farmers. <u>Outputs</u> Eberhard, J. (2020) Lime app and fertiliser extension in Cambodia. 2014/088 and 2016/237 ACIAR SALM X-Project Final Report Also see Activity 2.5

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
3.6	Disseminate experimental findings to smallholders and agricultural input suppliers, through the use of local media, farm field schools and regional extension officers (PC, A)	Increased knowledge of smallholders and agricultural input suppliers (Dissemination summary, event attendance counts, evaluation reports in Annual Reports)	September 2018 (September 2018) May 2019 (May 2019) May 2020 (May 2020)	Farmer field days related to lime and fertiliser management were held in Kampot (1) and Siem Reap (2) provinces (Cambodia) and Pakxapkao village, Vientiane Capital province (Lao PDR) during the 2018-2019 growing season. In both Cambodia and Lao PDR, farmer notes and/or videos that summarise key lime and fertiliser management recommendations were distributed by online social media avenues and/or in person (depending on COVID-19 restrictions) to farmers who both did, and did not participate in the project. <u>Outputs</u> See Activity 2.5
3.7	Evaluate the impact of adopting improved soil management technologies on crop yield, crop profitability and soil properties. (PC, A)	Development of adoption techniques for broader distribution (Evaluation in Final Report)	May 2020 (May	Financial costs and benefits of lime and improved fertiliser management in Cambodia were assessed by Ratana Tech (CARDI) and in Lao PDR by Kaisone Kivoravong (PAFO, Champasak). Examples have been included in the extension material and was presented at the field days in February 2020. Demonstration data collated annually by the CARDI team identified impact of lime application on yield improvements and potential crop profitability. The adoption of lime and recommended NPK fertilisers was found well aligned with the drivers of adoption noted from farmers' village discussions, and with livelihood factors. Strong interest in adoption of lime was noted in Objective 2 Final Review presentation (90-95% farmers in Cambodia participating villages). Adoption of lime was seen as improving soil quality and potentially could enhance profitability of farmers. Social/livelihoods benefits were assessed by Ratana Tech (CARDI) in Cambodia and in Lao PDR by Maiyer Xiong and Fongsamouth Southammavong (both NUOL). Project impacts are reported in this Final Report. Also see See Activity 2.6a
3.8	Publish data on soil management and yield responses in vegetables in journals and conferences (PC, A)	Research findings reported and communicated to science community (Publications, Conference presentations)	March 2020	Two posters presented at TropAg 2019 and abstracts published. Two journal papers in preparation. <u>Outputs</u> Eberhard, J., et al. (In Preparation) Balanced NPK fertiliser application improves yield and income of smallholder farms in Lao PDR and Cambodia. Hin, S. et al. (2019) Lime and Fertiliser Applications Increase Yield of Leafy Vegetable Crops in Cambodia. Proceedings 2019, 36, 179. Jones, S. et al. (In Preparation) Importance of managing soil acidity for smallholder vegetable farming in Lao PDR and Cambodia. Sisouvanh, P. et al. (2019) Evaluation of the Effect of Organic Fertilisers on Lettuce Yield in Lao People's Democratic Republic (PDR). Proceedings 2019, 36, 183.

PC = partner country, A = Australia

6.4 Objective 4: To develop improved management of irrigation in relation to soil-water status and crop requirements in various growth stages to improve crop yield and profitability.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
4.1	Conduct training workshop in field experiment design, implementation and management including data quality control. (A)	Built capacity within research partners and operational staff (Training attendance and evaluation, Trip Report)	October 2016 (June 2016)	(As per 3.1) Three training and planning workshops were conducted by Australian staff (2 USQ, 1 UTAS) in Lao PDR (HRC, Vientiane - 14 June 2016; Pakse, Champasak - 17 June 2016) and Cambodia (CARDI - 21 June 2016) on Experimental Design and Implementation covering aspects such as principles of experimental design, site characterization, record keeping, health and safety, and project-specific experimental layouts and treatments. A total of 30 (6 women and 24 men) project and non-project staff from the partner countries attended across all workshops. An impromptu training session on field experimentation (experimental design, data recording, interpretation etc.) was held for Pakse staff at the Agricultural Research Station for Southern Lao, km 35, Paksong on 25 Nov 2017. Local staff feedback on the training workshops was generally positive.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments **Note: Outputs are in English language unless otherwise stated in parentheses**
4.2a	Identify suitable simple weather and/or soil based irrigation scheduling tools (A)	Scheduling methods for use in field experimentation identified (Annual Reports)	June 2017 (September 2017)	Review of costs and benefits of soil moisture sensors completed. Evaluation of irrigation scheduling options was undertaken, including weather-based scheduling techniques based on 33 years of data from the NASAPOWER Project online climate database, simple evaporation pans (from 5 litre bucket to part of a 200 L drum), Watermark and G-bug tensiometric soil moisture sensors. A number of monitoring methods were tested at Koun Sat, Kampot province, Cambodia. An Excel workbook was developed to provide irrigation scheduling advice based on ET_c calculated from NASAPOWER Project data. A range of crop choices is given in the workbook. An example workbook was included with MTR documentation. Irrigation scheduling charts were developed from NASA Power climate data for each district/province in the project and were used for experiments and demonstration trials, which occurred in the 2017-18 and 2018-19 dry seasons. <u>Outputs</u> Touch, V. et al. (2017) Cambodia annual meeting Objective 3 & 4 Result Summary Kampot Hin, S. et al. (2017) Cambodia annual meeting Objective 3 & 4 Result Summary Siem Riep ACIAR SMCN 2014 088 (2019a) Daily application tables for irrigation of leafy vegetables in Cambodia. Technical Note (Khmer, English) ACIAR SMCN 2014 088 (2019b) Daily application tables for irrigation of leafy vegetables in Lao PDR. Technical Note (Lao, English) ACIAR SMCN 2014 088 (2018d) ETc Irrigation Calculator. Siem Reap example. MS Excel Technical Aid. Uddin, J. and McPhee, J. (2018) Progress on irrigation activities (Objective 4) for ACIAR project SMCN-2014-088
4.2b	Conduct baseline soil moisture and irrigation monitoring (PC, A)	Preliminary soil moisture and irrigation data captured. (Annual Report)	June 2017 (May 2017)	Baseline data collected (e.g. irrigation system capacity, water application amounts, timing, infiltration rates, distribution uniformity, soil moisture monitoring etc.) to help design irrigation experiments. Protocols for irrigation experiments were prepared and provided to country partners. An Excel worksheet was developed for recording data from infiltration, distribution uniformity and system output tests. This was reviewed and updated mid-project to overcome interpretation confusion and problems of correct data recording. A decision was made to monitor soil moisture and irrigation water application using farmer practice in crop season 1, followed by testing of irrigation scheduling treatments in subsequent seasons. Soil moisture data were not recorded correctly in many sites due to malfunctioning of sensors, poor installation and lack of knowledge of local staff. Collection of correct infiltration rate data also proved problematic, with numerous strange results. Early progress in this area was slow due to lack of confidence on the part of partners in pursuing alternative irrigation scheduling strategies. Some experimental work failed due to seasonal factors. <u>Outputs</u> ACIAR SMCN 2014 088 (2018c) Distribution Uniformity-Infiltration Calculator - MS Excel Technical Aid.

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
4.3a	Undertake field site selection (PC, A)	Experimental and demonstration sites short listed and selected	October 2016 (June 2016)	Three Australian staff visited 12 vegetable farms in Lao PDR (6 each in Vientiane and Champasak provinces), and 10 in Cambodia (6 in Siem Reap province, 4 in Kampot province) from 11 – 24 June 2016 to finalise selection of replicated and demonstration field experiment sites based on 18 selection criteria. After visits, discussions and scoring against selection criteria of potential sites for field experiments, field demonstrations and village socio-economic analysis, a shortlist of recommendations was made. Details of sites used during the project are given in Table 1.
4.3b	Establish replicated experimental field trials to assess alternative irrigation scheduling methods in relation to crop growth and development (PC, A)	Treatments set up and crops established Basis of extension messages (Annual Reports)	i. March 2017 (1st season) (May 2017) ii. December 2017 (2nd season) (March 2018) iii. December 2018 (3rd season) (February 2019) iv. December 2019 (4th season) (n.a.)	Conducted one replicated trial in 2016-17 season in Siem Reap, Cambodia with different irrigation and nutrient treatments where the irrigation treatments were designed based on weather-based irrigation scheduling technique, which worked well. This trial was conducted in conjunction with project ASEM/2012/081. A replicated experiment in Kampot, Cambodia was abandoned after being flooded twice. Further replicated experiments were established as follows: • 2017-18 - NUoL, Vientiane and Lao-Viet Research Station, Paksong (in Lao PDR) and Tuek Vil Experiment Station, Siem Reap (Cambodia). • 2018-19 - NUoL, Vientiane, (in Lao PDR) and CARDI, Phnom Penh (Cambodia). Due to the lack of confidence on the part of partners regarding the impact of changing irrigation schedules, only one replicated experiment was established in the early years of the project. To allow local partners to develop confidence in the scheduling techniques, it was decided to re-locate irrigation experiments to research farms for one or two seasons starting in 2018, as noted above. This led to planning of irrigation experiments at Tuek Vil Experiment Station (Siem Reap, 2018), CARDI (Phnom Penh (2019), km35 Agricultural Research Station for Southern Laos and Lao-Viet Agricultural Experiment Station (Paksong, 2018) and National University of Laos (Nabong campus, 2018, 2019) Of these, only the two years of experiments at NUoL were successful. All the other sites were either not established due to delays which prevented site establishment before onset of the wet season, or failed after establishment due to seasonal and site factors, such as excessive weed burdens, unseasonal rain and lack of staff resources. Outputs Hin, S. et al. (2018) ACIAR SMCN 2014 088 CARDI Demonstration site report 2018 Hin, S. and Touch, V. (2019) ACIAR SMCN 2014 088 CARDI Demonstration site report 2019 Hin, S. et al. (2019) Objective 3&4 Demonstration trial report. Presentation Melland, A. et al. (2018) ACIAR SMCN 2014 088 Annual Report 2018 Melland, A. et al. (2019) ACIAR SMCN 2014 088 Annual Report 2019 Somphou, I. et. al. (2018) Replication Experiment of Water management in lettuce plantation in Lao PDR. Technical Report Somphou, I. (2019) Water management in lettuce plantation in Lao PDR. Technical Report

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
4.3c	Monitor and report on replicated irrigation trials	Data on crop yield and quality collected and analysed Preliminary extension messages developed (Annual Reports)	i. July 2017 (1st season) (July 2017) ii. July 2018 (2nd season) (June 2018) iii. July 2019 (3rd season) (May 2019) iv. May 2020 (4th season) (n.a.)	Preliminary data from the replicated trial at Siem Reap in 2016-17 season showed that varying water application at different stages of crop in response to calculated crop demand could give better crop growth and yield compared to the farmer's practice of applying the same amount of water daily throughout the cropping period. Data from the 2017-18 irrigation x lime NUoL experiment were presented at the Mid-term Review. The 2018-19 NUoL trial (3rd season) showed that irrigation treatments managed on predicted ET_c, used half the water and labour, and gave yield increases of 26-72%, although high data variability meant there were no statistically significant differences. Irrigation WUE improved 2-3 fold. Outputs Hin, S. et al. (2017) Cambodia annual meeting Objective 3 & 4 Result Summary Siem Riep Somphou, I. et al. (2018) Replication Experiment of Water management in lettuce plantation in Lao PDR. Technical Report
4.4a	Establish demonstration field trials to assess alternative irrigation scheduling methods in relation to crop growth and development (PC, A)	Data on crop yield and quality Data on site responsiveness to inputs Basis of extension messages (Annual Reports)	i. March 2017 (1st season) (n.a.) ii. December 2017 (2nd season) (March 2018 iii. December 2018 (3rd season) (February 2019) iv. December 2019 (4th season) (n.a.)	Farmer demonstration sites established for lime and NPK (Objective 3) in 2017-18 were used to gather information on irrigation application rates. This showed applications ranging from below crop demand to 150-200% above crop demand. Farmer demonstration sites were established in Cambodia in 2018-19 to demonstrate alternative irrigation treatments. There were 6 sites in Kampot province (3 using alternative irrigation approaches) and 5 in Siem Reap province (2 using alternative irrigation approaches). No farmer demonstration sites using ET_c predicted irrigation demand were established in Lao PDR. Extension messages were developed based on the results of the NUoL experiments in 2017-18 and 2018-19 seasons. At least 50 farming households have eagerly adopted the approach of watering once per day and were pleased to see they could reduce water use and labour by ~60% without negatively impacting yield. However, in some cases the message has become over-simplified to 'water once a day', which is only correct advice if the original practice had been to apply twice as much water as needed. Fortunately, as demonstrated by early base line data gathering, this was the case in many situations. However, the over-simplification of the message has an element of risk attached to it, in that it does not cater for changing demand over the season or the life of the crop, or an understanding of how much over (or under) watering was originally occurring. This situation initiated the development of a nomograph to allow easy calculation of the amount of water to apply in a given situation. Outputs Hin, S. et al. (2018) ACIAR SMCN 2014 088 Demonstration Site Report July 2018

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
4.4b	Maintain demonstration trials	Data on crop yield and quality collected (Annual Reports)	i. July 2017 (1st season) (n.a.) ii. July 2018 (2nd season) (April 2018) iii. July 2019 (3rd season) (March 2019) iv. May 2020 (4th season) (n.a.)	Farmer demonstration sites were maintained in Cambodia in 2018-2019 (3rd season) to demonstrate alternative irrigation treatments. The sites were as detailed in Objective 4.4a. These sites showed 2.5-fold improvements in WUE using watering cans (Kampot) and hand-held hoses (Siem Reap). Outputs Hin, S. and Touch, V. (2019) ACIAR SMCN 2014 088 CARDI Demonstration Site Report 2019 Hin, S. et al. (2019) Objective 3&4 Demonstration trial report. Presentation
4.5	Conduct training of local Government and other extension services staff improved irrigation management practices (PC, A)	Improved capacity of extension staff (Training attendance and evaluation, Trip Report)	i. December 2016 (December 2016) ii. May 2019 (May 2018) iii. May 2020 (February 2020)	Two workshops were conducted (HRC, Vientiane, Lao PDR - 1 Dec 2016; CARDI, Cambodia - 6 Dec 2016) on fundamentals of Soil and Irrigation including field-based demonstration of the determination of soil type, texture and structure, soil profile, water-holding capacity of soil, irrigation system capacity, uniformity etc. The workshops were conducted jointly by Robert Hoogers (from sister project ASEM 2012/81), Jasim Uddin (USQ) and Suzie Jones (UTas). A total of 25 local staff from NAFRI, HRC, CADC, PDA attended. A second round of similar soil and irrigation training was delivered in May 2018. In addition to formal and planned training and capacity building sessions, numerous informal 1 on 1 sessions occurred throughout the project during visits and online which provided training for in-country scientists on research methods and analysis, irrigation strategies and scheduling calculations. A workshop was conducted at NUoL, Lao PDR in November 2018 to train farmers in understanding water holding capacity of different soil textures. Attendance comprised of 2 farmers from Pakxapkao, 2 farmers from villages in Champasak and 2 research and PAFO staff from Champasak Province. After the development of the nomograph and worked training examples, training in the use of the technique was delivered in Feb 2020 to 10 CARDI staff in Phnom Penh and 7 PDA staff in Kampot province (Cambodia), and 3 NUoL and HRC staff in Vientiane (Lao PDR). The training for PDA staff in Kampot province was delivered by one of the CARDI staff who was trained the previous day in Phnom Penh. There was general enthusiasm amongst the staff for the use of the application tables and nomograph technique. There is a need for further exposure and training related to the use of the nomograph for irrigation scheduling, particularly of provincial agricultural extension staff in Cambodia, and HRC/NUoL and agricultural extension staff in Lao PDR.

4.6	Develop simple technical support guidelines for irrigation (PC, A)	Support tools for extension staff developed Improved capacity of extension staff (Irrigation management guidelines in extension format)	December 2019 (March 2020)	Key irrigation scheduling recommendations were developed as key extension messages for farmers. The messages were developed into Khmer and Lao Farmer Notes. Simplified irrigation scheduling charts were prepared for each district/province involved in the project for a range of crops characterised by growth habit and duration – e.g. 30, 45 and 60 day leafy vegetables. These can be reproduced in hard copy. An Excel-based data recording and calculation workbook was developed for use in conjunction with infiltration, distribution uniformity and irrigation system output tests. Daily application tables and an irrigation scheduling Excel workbook for each province/district were provided to project partners at the time of the mid-term review. It was known at the time that there was a serious gap in the information and capability available to farmers to enable adoption of the new information about more efficient irrigation scheduling. This gap was addressed in late 2019 with the development of a nomograph that allows a user to calculate irrigation requirements based on the Daily application tables and other simple data readily available to farmers, such as the dimensions of the crop bed, the type and age of the crop and the transplanting date. This was supported by a number of worked examples for both countries. All materials were translated and are available in English, Khmer and Lao. A narrated powerpoint presentation demonstrating the use of the daily application tables and the nomograph has been produced in English and plans are underway to enable production of Lao and Khmer versions. Outputs Extension materials ACIAR SMCN 2014 088 (2019a) Daily application tables for irrigation of leafy vegetables in Cambodia. Technical Note (Khmer, English) ACIAR SMCN 2014 088 (2019b) Daily application tables for irrigation of leafy vegetables in Lao PDR. Technical Note (Lao, English) ACIAR SMCN 2014 088 (2020c) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Technical Note (Khmer, English) ACIAR SMCN 2014 088 (2020d) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Technical Note (Lao, English) ACIAR SMCN 2014 088 (2020e) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Training presentation (Khmer, English- narrated) ACIAR SMCN 2014 088 (2020f) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Training presentation (Lao, English - narrated) ACIAR SMCN 2014 088 (2018c) Distribution Uniformity-Infiltration Calculator. MS Excel Technical Aid ACIAR SMCN 2014 088 (2018d) ETc Irrigation Calculator. Siem Reap example. MS Excel Technical Aid ACIAR SMCN 2014 088 (2020h) Irrigation nomograph master. Technical Note (English-Khmer, English-Lao) Also see Activity 2.5

No.	Activity	Outputs/ milestones	Due date (Completion date)	Achievements/Outputs/Comments Note: Outputs are in English language unless otherwise stated in parentheses
4.7	Extend experimental findings to smallholders and agricultural input suppliers (PC, A)	Increased knowledge of smallholders and agricultural input suppliers Adoption of improved irrigation management practices (Annual and Final Report)	i. September 2018 ii. May 2019 (March 2019) iii. May 2020	Farmer field days related to irrigation scheduling were held in Kampot (1) and Siem Reap (2) provinces (Cambodia) and Pakxapkao village, Vientiane Capital province (Lao PDR) during the 2018-2019 growing season. Farmer notes that summarise the yield and water use benefits of changing irrigation management, and training materials (including a video) on the use of the Daily Application tables and the irrigation nomograph, will be distributed by online social media avenues to farmers who participated in the project, and post-COVID-19 will be distributed in hard copy to farmers, PAFO & DAFO; input suppliers, NGOs in Lao PDR. A video demonstrating the use of the daily application tables and the nomograph has been produced in English and plans are underway to enable production of Lao and Khmer versions. Also see Activity 2.5 Outputs See Activity 2.5
4.8	Evaluate the impact of adopting improved water management technologies on crop yield, costs of production and crop profitability (PC, A)	Development of adoption techniques for broader distribution (Evaluation in Final Report)	March 2020	Extension material collated for distribution to farmers included the results of evaluating the impact of new irrigation strategies on water use (60% saving in water use from using new irrigation strategies), identifying that there are savings that can be made in time and labour (through less time to irrigate), identifying 2-3 fold increase in water use efficiency, and identifying no yield losses from adoption of the new irrigation strategies. The project has demonstrated this information and simple adoption strategies through inspection of demonstration trials and provided this information as presentations to farmers at field days and in handout material. There are plans to distribute this information and simple adoption strategies to village farmers (post COVID) in hard copy and online to a broader audience. Also see Activity 2.6a
4.9	Publish data on soil management and yield responses in vegetables in journals and conferences (PC, A)	Research findings reported and communicated to science community (Publications, Conference presentations)	March 2020 (November 2019/on-going)	Poster presented at TropAg 2019 and abstract published - ‘Evaluation of the effect of lime and irrigation on lettuce yield in Laos’ and conference abstract by the same title published. One paper (working title ‘Irrigation scheduling methods for smallholder vegetable farmers in Cambodia and Lao PDR’) is in preparation, target journal either Irrigation Science or Agricultural Water Management. Outputs McPhee, J. et al. (2019) Evaluation of the Effect of Lime and Irrigation on Lettuce Yield in Laos. Proceedings 2019, 36, 185

PC = partner country, A = Australia

7 Results and discussion

7.1 Vegetable input supply chain constraints and opportunities (Objective 1)

7.1.1 Cambodia

Input supply and farming systems research considered the range of inputs into vegetable production systems in Cambodia and the ability of the local input supply chain to provide these and adapt to meet future requirements. This was informed by interviews with suppliers in March 2018, a farming systems survey of 120 vegetable farmers in January 2017 and focus group discussions with over 130 farmers in 2017, 2018 and 2019 at field days. Data is presented in Starasts et al. (2020) Vegetable Input Supply Chain Analysis – Cambodia Technical Report.

<u>Seed</u> - Vegetable farmers purchased approximately between 1 and 20 g of vegetable seed varieties for vegetable cropping. Forty two percent of Koun Sat village participants kept some of their seed for future crops. The major source of information nominated by participants about the seed was the farmer or local shop.

<u>Seed constraints</u> - Suppliers indicated they have difficulty obtaining high quality, newer seed varieties or seed varieties adapted to local conditions. They indicated that poor seed quality and low germination were problems they faced when seed was kept over several seasons. Most suppliers did not store seed material as they did not have appropriate cold room storage facilities. Suppliers indicated that local farmer-bred varieties were well-adapted to the climate and higher temperatures and were able to be stored for longer. Suppliers suggested they should return poor quality seed to their supplying companies.

<u>Labelling</u> - The study found that some seed, fertiliser and pesticide companies did not translate product labels to the national Khmer language on the pack. Farmers who purchase these products would have difficulty finding out information on the pack about expiry date of product, seed germination, seed purity, moisture content, harvesting maturity, and recommendation rate for application, method of application, safe handling of the product or the withholding period prior to vegetable harvest.

<u>Organic fertiliser inputs</u> - Almost all farmers in the study used organic fertilisers (manures) to improve the soil. Volumes between 100 and 2500 (up to 6000) kg of cattle manure are used annually by participant farmers. Those who purchase manure, purchase between 10 and 10 000 kg at a time. If purchased, these manures were purchased mostly once per year, and usually prior to vegetable planting. The rates required and nutrient content and availability of various animal manures varies significantly as does the moisture content – making it difficult to accurately provide a particular rate of nutrients. Collecting, transporting and composting animal manure throughout the year is labour intensive, although the volumes of manure obtainable from one cow per year appear to be sufficient to provide some soil benefit in most operations. Additional animals would require access to more land and calculating the rates of these would be difficult.

<u>Chemical inputs</u> - All participants except two used chemical fertiliser. Indications from farmers in focus discussions is that fertiliser use is considered high. Farmer reasons for their application rates included to obtain higher yield, better product and increased income. Farmers requested information to enable them to apply appropriate fertiliser rates to their vegetable crops. Field day discussions indicated that farmers had concerns for the environmental effects of the high fertiliser rates they were applying.

Farmer information needs - Village discussions held at field days in 2018 and 2019 identified that farmers were requesting information on how to grow vegetables, how much and how to apply fertilisers including lime, and information about sources of lime, and on pest management. Farmers suggested they did not know where to purchase lime and a second set of interviews in 2019 with input suppliers led to collation of lime availability data (Starasts et al., 2020).

Access to vegetable inputs - As an example of farmer access to input supplies, Focus group discussions with farmers indicated that in Koun Sat village the Roung market was 1-2 km from farmers but was unable to supply all their inputs. Farmers in Trapeang Chhrey indicated they could only purchase their required inputs from Choukk markets which was 3.5 km away from their village. In Siem Reap the Angrong market was a 6 km round trip for Ta Trav farmers to visit supply shops to purchase input supplies. Farmers transport their inputs mainly by motorcycle and animal-drawn vehicles. This may limit their ability to purchase products such as lime in large sizes or in bulk.

Supply shops – Supply shop owners were well experienced in business. In Kampot, the average age of suppliers was 49 years, six of whom were female and five were male. Suppliers had on average twelve years of business experience and education levels ranged from primary school, secondary school, high school, and tertiary. In Siem Reap, the average age of suppliers was 47, with 4 of the 5 suppliers interviewed being male. Education levels included primary and secondary school, and suppliers had approximately 12 years on average business experience.

Suppliers in the study indicated they purchased products from businesses registered with the Ministry of Agriculture, Forestry and Fisheries (MAFF) including MALYSAN GROUP Co., East-west, KASEKOR CHAMROUNPHOL, EAGLE, CHIATAI, and GREEN SEED Companies. Some purchased products from businesses that were not registered with MAFF.

Financial constraints – Suppliers in both provinces indicated that the micro scale of smallholder vegetable production meant very low market demand for input supplies. They also indicated that some farmers were not able to afford to pay for vegetable production inputs on time. Farmers often were owing suppliers money when they bought input supplies and did not pay suppliers until after the crop harvest. Suppliers indicated this did not provide them with sufficient funds to make payment to their wholesale company, therefore delaying their payments to supplying companies.

Suppliers suggested that access to affordable credit for input supplies should be available to all farmers if they develop ongoing relationships with MicroFinance Institutions, and through an embedded service of collector and input suppliers. Farm survey data indicated that less than 7% of participating farmers borrowed funds to pay for vegetable input supplies and 91% used their own funds to pay for input supplies. Suppliers suggested that farmers use family assets to source microfinance in order to purchase input supplies and seed material from market suppliers to support vegetable production. They indicated that some farmers already source finance for off-farm requirements including family consumptions and business set up.

Information for suppliers - Suppliers of agricultural input material indicated they did not have experience in agronomy, and were reliant on information about agricultural technologies and production from representatives from supplying companies. Input suppliers sourced technical information from Seed, Fertiliser, Pesticide and Irrigation Equipment Companies, and the Provincial Department of Agriculture service (PDA). Suppliers sourced almost all technical information about vegetable production from the international companies from which they import seed from Thailand, Vietnam and China.

Information for farmers - In Kampot Province, only two seed and two pesticide suppliers indicated they provide information about vegetable agronomy and technologies directly to farmers when they accept their business. In Siem Reap in Ang Krong Krabey Real and Puok markets, five of the input suppliers indicated they supply technical information to farmers about vegetable growing. Suppliers suggested they required more training (for themselves) but also that farmers were too busy to attend training.

7.1.1.1 Discussion

Key issues identified in the input supply analysis are discussed in terms of strengthening supply chains in order to reduce risks, enhance productivity and profitability for businesses, and contribute to the sustainability of vegetable production.

Availability of information in supply shops - The study findings suggest that information about vegetable production, especially crop nutrition, pests and diseases and the application of agricultural chemicals could be available in supply shops to service farmers' information needs. This includes recommended rates, situations, application methods, safety and handling and withholding periods. The study also suggests there may be a role for vegetable market sellers in contributing to information flows and building capacities among the farmers and stakeholders.

Recommended fertilisers - Farmers want to purchase the appropriate fertiliser products from their supplier at an affordable price and this will contribute to their ability to produce products sustainably and profitably. Suppliers therefore need access to quality technical information about appropriate products and rates for local conditions. Chhun et al. (2012) found widespread mis-application of fertilisers due to inadequate knowledge and skills amongst farmers, extension staff and private sector sales staff from agricultural suppliers. Vuthy et al. (2014) found that fertiliser quality issues and mis-stated nutrient contents on some packaging resulted in some mistrust among farmers in the fertiliser market.

Registration, product labelling and food safety - Some product labels were not in Khmer language, limiting the purchaser's ability to appropriately and safely apply some products. It is suggested that appropriate Khmer labelling be a requirement for registration of products and importing companies. This will help to ensure that products meet food safety, organic or safety standards. VSAT (2016) similarly found a need for responsible pesticide registration, storage, distribution and use in their Myanmar study.

Finance - Difficulties where farmers are making late payments for their purchases are leading to difficulties for suppliers to pay wholesale companies. Suppliers suggest that if farmers access microfinance to pay for input supplies, this would enable suppliers to make payments on time to wholesale companies. VSAT (2016) again identified key areas for improvements in input supply chains including vegetable farmers' access to credit (p.10). These authors suggest there is a need for financial institutions with an understanding and a long term interest in the vegetable sector's growth. Demand for finance within agriculture may be limited because of high costs for borrowers and the high risks due to variability of incomes. In addition, limited information, tools or appropriate collateral reduce the supply and demand for finance (USAID, 2010). FAO (2001) however, suggest that poorer households may be willing and able to service loans if they borrow for their own perceived needs and are adequately screened and monitored.

Reliance on supply chain – A strong reliance by farmers on local suppliers and by local suppliers on companies brings risks in terms of dependence on available products and prices especially in local cases where many farmers are only aware of and working with their local suppliers. This may potentially create vulnerabilities in terms of product access or price fluctuations. VSAT (2016) suggests that it is important for transaction costs associated with input supplies, technical support, certification, and crop marketing to be minimised. These authors suggest producer organisations or contract farming may help to minimise such costs.

Seed storage and quality - Limitations in terms of seed storage infrastructure among local input suppliers creates a risk for suppliers and farmers in terms of access to quality products. A collaborative approach between stakeholders in local areas may lead to, for example, shared access to infrastructure for seed storage by local suppliers, ensuring quality seed products and contributing to reducing risks in vegetable production, and enhancing competitiveness and sustainability.

7.1.1.2 Recommendations for improving vegetable input supply chains

A series of recommendations is developed which may contribute to outcomes associated with reducing risks, and enhancing knowledge and practices (Radhakrishna & Bowen, 2010) in vegetable input supply chains. These recommendations are incorporated into a series of letters drafted for key stakeholders working to support and facilitate vegetable production including input suppliers, Ministry of Agriculture, Forestry and Fisheries, Provincial Department of Agriculture staff, Non-Government and farmer organisations and other projects.

Fertilisers and pesticides

That the Provincial Departments of Agriculture (PDA) ensure that input suppliers supplying vegetable farmers are aware of appropriate fit-for-purpose fertilisers and pesticides for use in vegetable production. In particular, and in relation to this project, this includes:

- The benefits from application of agricultural lime products to vegetable producing soils and sources of appropriate products.
- That there are recommended NPK mixes for growing vegetables and that suppliers try to sell the recommended mixes.
- All fertiliser and pesticide products must have labels in Khmer language including appropriate application, safety and withholding information.

That PDA ensure that local input suppliers and vegetable farmers have contact details of Government or private sector project staff or office who can advise them in relation to appropriate products especially in relation to registered and appropriate pesticides, and advise in relation to online sources of information.

Seed

That the Ministry of Agriculture, Forestry and Fisheries (MAFF) work with wholesale suppliers to create initiatives and projects for locally adapted, improved vegetable seed varieties and new products and technologies for improved production in line with local climates.

That MAFF work with local input suppliers and warehouses and wholesale suppliers to work towards availability of seed storage capacity in regional areas.

Information and training

Wholesale suppliers could provide supply shops with information on their pesticide and fertiliser products in relation to application rates and methods, safety and withholding periods in hardcopy or other format (in Khmer language) which input supply shops should then make available to farmers.

Input suppliers could act as a local source of technical information to provide to farmers. This could include hard copy, contact details or online websites links.

Input suppliers take on a communications role, whereby they collect information about farmer problems and needs and share this information with PDA and wholesale companies. New information relevant to vegetable production (from PDA or companies) is provided to suppliers who provide this to farmers. Suppliers can also request PDA or wholesale companies to organise training for local farmers in relation to their needs.

NGOs and local projects could be an information channel for vegetable production technical information (from wholesale companies and PDA) to be shared with local farmers. Vegetable sellers could also distribute (hard copy) information to farmers.

Wholesale companies, PDA, NGOs and local projects could incorporate training opportunities for local vegetable farmers about pest management, irrigation strategies, post-harvest handling and packing of vegetables when opportunities arise.

PDA could take a lead role to develop and maintain a website portal of vegetable agronomy and post-harvest information and to promote the URL and new information to farmer leaders, companies, NGOs, local project staff and input suppliers.

Credit and payment plans

Vegetable sellers could be a source of (hard copy) information about microfinance which could be made available to farmers during visits.

Microfinance services could be promoted to farmers as a means to pay for input supplies.

PDA might facilitate some collaborative negotiation between input suppliers and wholesale companies in terms of payment plans to cover costs of input supplies.

Labelling of products and registration of suppliers and products

Appropriate labelling and registration of agricultural products (including international companies) within the Department of Agricultural Legislation, along with registration of input suppliers will help improve communication and awareness in relation to products, application, and human and food safety with in vegetable production.

Vegetable production network and contact details

PDA staff could form a network, initially by maintaining a list of company and local supplier contacts and farmer leaders to support the generation, sharing and discussion of new information relevant to the future development of input supply chains and vegetable production. Examples include ensuring suppliers are up to date with new initiatives, new product registrations and other regulations in relation to provision and sale of products. An example of this is to ensure all wholesale suppliers and local input suppliers are aware of the benefits of lime application to many vegetable growing soils, also that there are recommended rates for NPK for vegetable soils. Such a network could also serve to collect information to estimate the future demand and identification of transport issues and initiatives relevant to input supplies or vegetable sales. NGOs and local project staff with an interest in vegetable production could be included in this network.

7.1.2 Lao PDR

The input supply chain for vegetable production in Lao PDR was reported in detail by Bonney et al. (2020, in ACIAR SMCN 2014 088 Final Report Objective 1 Lao PDR). The upstream input supply chain is quite opaque and that appears to be due both to business confidentiality and the main suppliers being in external countries. There is no manufacturer of inputs in Laos, except white lime. Laos has reserves of rock phosphate.

Input supply chain mapping in Vientiane and Champasak provinces in Lao PDR demonstrated the reliance of Laos agriculture on imports from Thailand and Vietnam and also, in some instances, how opaque the input supply chain is due to the lack of information, particularly when imports of foreign-produced fertilisers and agricultural chemicals is concerned. In other instances, such as with identifying the source of animal manure supplies into the Paksong District in Champasak, quite short, simple supply chains were identified from the neighbouring Saravanh District of Saravanh Province and dispelled the hypothesis that animal manures were being sourced from Vietnam.

Seed - Most of the varieties and sources of seed appeared to come from Thailand and some from Vietnam. In most districts few farmers were collecting their own seed with Huaha village, Hadxayfong District near Vientiane having the highest proportion doing so (66%), probably because of the greater diversity of crops grown in that area. Overall, farmers claimed to have the following problems with their seed supply (n=105):

- 52% - appropriate seed variety;
- 57% - germination rate;
- 42% - trueness to type;
- 38% - seed-borne diseases;
- 48% - growth rates;
- 33% - seed availability.

Fertilisers - Half the interviewees claimed they were using regular ‘organic’ practices (mainly rice husks and manure) and 10% were using lime. The volumes purchased ranged from approx. 200 kg to 1500 kg with purchases usually being only once or twice a year. Overwhelmingly farmers used animal manure because they thought it improved the soil condition, made their crops grow better and that it was cheaper (rank order). 27% did so because they associated animal manure with being ’organic’. The major complaint about fertiliser inputs was the lack of availability of manure in some areas.

The artificial fertilisers purchased in any specific village or area tended to be aligned with the type of crop suggesting that specific fertiliser recommendations were being received by the farmers from their supplier. This was explicitly supported by farmers’ responses. The most common bag size purchased was 50 kg and whilst prices varied from district to district (probably due to transport costs) they tended to be similar within one local area. The most common fertiliser mixes were (n=105):

- 29% used urea (46:00:00)
- 28% used 16:20:00
- 23% used 15:15:15

Selling price:

15:15:15 = 220000 kip/bag (50 kg)
16:20:00 = 175000-180000 kip/bag (50 kg)
18:08:08 = 160000 kip/bag (50 kg)
46:00:00 = 160000 kip/bag (50 kg)

Inorganic fertiliser was purchased in a wide variety of pack sizes from 5 – 50 kg and up to 1.5 – 6 tons per year mostly at two or three-monthly intervals through the main growing season and overwhelmingly from the same store. The main reasons for a stable purchasing source was largely trust and close proximity to their farm. Only 12% thought that the purchase price was not a fair price. Inorganic fertiliser appeared to be sourced almost exclusively from Thailand and only 40% of farmers could identify the source of their inorganic fertiliser.

51% of farmers received information from their suppliers about the best fertiliser for their need and 49% of farmers received information about the specification and quality of their inorganic fertiliser (n=105). Farmers identified a number of perceived problems with the inorganic fertiliser they had purchased:

- 47% stated they’d had trouble with fertiliser bags being labelled only in Thai;
- 42% had some trouble obtaining fertiliser when they wanted it;
- 19% claimed to have had problems with the growth rate of their crops with inorganic fertiliser;
- 18% claimed problems with contaminated fertiliser;
- 15% were applying lime or gypsum to their land, mainly white lime.

Pesticides - It appears that 90% of farmers are using some form of pest control (n=105), purchased in small package sizes with an annual consumption of 500 g to 5 kg and a frequency of use approx. 1-3 times per month during the growing season. Types of pesticide used are as follows:

- 61% were inorganic pest control chemicals only and largely this included herbicides, insecticides and fungicides;
- 21% were using both organic and inorganic pest control;
- 2% used biological controls only;
- 10% claimed to be using no form of pest control.

Purchase patterns and reasons are similar to other inputs – local and on the basis of trust and convenience. Only 34% knew the source of their pesticides and that appears to be predominantly Thailand. 48% receive information from their supplier about how to use the pesticide and the safety procedures. Despite this, when asked to name the main source of information about pesticides, most nominated family members, then the local supplier followed by a small minority receiving information from their local extension agent. In Pakse, being closer to Vietnam, there appears to be more pesticides sourced from that country. There are few complaints from farmers about pesticides and if there are perceived problems it is not clear whether this is through inaccurate or inappropriate usage.

Other - Irrigation equipment appears to be a major cost for farmers with an average of kip 430,000 being spent annually on irrigation equipment, in part because a lot of items (e.g. buckets and hoses) appear to have a short life on the farm. Fuel is another major cost item with the average farmer spending just over kip 700,000 p.a. on fuel. A few farmers nominated costs of bags as an input for their vegetable production and marketing.

Suppliers - The input suppliers interviewed appeared to be younger than the average age of farmers although this is an observation and no valid statistics were available. Those interviewed gave similar information to that received from farmers.

Bulk purchases are possible but small or no discounts are available because store owners claim the products are discounted already and the margins are low. The sources of the main inputs are Thailand and Vietnam. In the view of suppliers, farmers rarely ask for information about their input supplies and yet farmers need to understand much more about the inputs they use and how to use them and their equipment correctly and safely.

Importers / Manufacturers - The importers/manufacturers interviewed appeared to be younger again than the average age of farmers and supply store owners although this is an observation and no valid statistics were available. Those interviewed gave similar information to that received from farmers and local supply shops.

Importers/manufacturers provide no information to their buyers (farmer supply stores) and claim that the regulations and administration to import these supplies is quite onerous and takes a long time, often slowing supply to the users. They know of no problems or complaints about their products.

Manure - The main animal manures used in horticultural production in the Paksong District of Champasak are cattle and chicken manures. Very little manure from other animals appears to be used. It appears that the rapid growth of large horticultural enterprises in the last 10 years and particularly the last 3-5 years in the Paksong District has increased the demand for animal manure. There is an absolute shortage of manure produced in the district. The main local Paksong suppliers are 3 large cattle farms including a Government operated farm, as well as a large poultry farm, however, there are about 10 farms of 50 cattle or more in the district. Chicken manure is regarded as the best because of its higher level of nutrients (mainly nitrogen) and where used it is mainly sourced from a large chicken producer in the Pakse District.

Apparently, there is no registration necessary for manure trading and PAFO officers were of the view that some form of registration should be required for the control of the movement of animal diseases between regions. PAFO officers in Pakse, Paksong and Saravanh as well as farmers were unanimous that there does not appear to be any movement of cattle manure across the border from Vietnam. The reasons cited included that the distance makes it too expensive and that there is a shortage within the mountain coffee growing areas of Vietnam.

In the livestock districts almost all farmers will sell their manure. The price received by the cattle livestock farmer is approximately kip 5000 per 28 kg bag. Chicken manure sells for kip 2800000 per ton. It appears that there is a widespread belief by farmers that animal manure is “better for the soil” and “lasts longer”. McRoberts (2015) in a study of the cattle manure supply chain from the central coast of Vietnam to the coffee areas in the Vietnamese Highlands adjacent to this area found that nitrogen in cattle manure is 3.5 times more expensive than nitrogen in urea and that organic matter in manure is 1.2 to 1.5 times more expensive than organic matter in commercial amendments.

7.1.2.1 Discussion

The major challenges to the vegetable input supply chain in Lao PDR are the lack of information flows and lack of control by the relevant authorities.

1. Inorganic fertilisers are required to gain import licenses but it appears that the information provided by manufacturers outside of Laos is minimal. It does not appear that there is effective monitoring and control of imports to the country for compliance with chemical specifications and efficacy. Importers do not appear to be compelled to ensure that usage data is provided to farmers in the Lao language. Little extension material for farmers is provided by importers. Importers do not appear to seek feedback or to test inorganic fertiliser efficacy.
2. Farmers receive little information about the efficacy or usage instructions for their input supplies *per se* and, in particular, inorganic fertilisers. This potentially leads to wastage, usage of fertilisers with inappropriate nutrient balance and potential toxicities (and for pesticides potential chemical residues) through over-application.
3. The strongest relationships in the chain are between farmers and the local stores where they buy their input supplies. These relationships are more community allegiance-based than based on the quality of the support received. Stores sometimes provide usage information but they are rarely trained in agriculture and so can only provide what the local extension agency or the importer provides them. The farmers rarely give feedback on efficacy or problems to the stores.
4. The supply chain relationships are based on informal relationships rather than a mix of formal (contracts) and informal (incentives/disincentives, relational contracts and standards).
5. The animal manure supply chain is an informal supply chain and the authorities have little information and therefore ability to monitor, control and develop the chain to support the Agricultural Development Strategy 2011-2020 (Ministry of Agriculture and Forestry, 2010).
6. The transfer of animal manures between districts and provinces is potentially a significant source of transferring animal diseases and parasites.
7. There appears to be little understanding amongst farmers and extension officers of the relative cost per unit of each of the main nutrients (nitrogen, phosphorus and potassium).
8. The Lao PDR Government has a commendable ‘organic agriculture development’ objective in its *Strategy for agricultural development 2011 to 2020: sector framework, vision and goals - agriculture and forestry for sustainable development, food and income security* (Ministry of Agriculture and Forestry, 2010). However, the cost of compliance for

small to medium sized businesses is considerable. This is exacerbated by the lack of a premium within Laos for organic produce despite there being a widespread recognition by consumers and many in the chain that "organic is better". In part, this relates to the lack of an organic or low-input 'brand' and also fundamentally to consumers' ability to pay such a premium. Consequently, it is only the foreign-owned larger farms that export to Western Europe or Japan that benefit from animal manure and low-inputs.

7.1.2.2 Recommendations for improving vegetable input supply chains

- Lao Government should consider ways of obtaining Foreign Direct Investment to enable the exploitation of rock phosphate reserves.
- A Lao PDR Government testing agency for agricultural supplies be established or, if it already exists, that its budget and capability be expanded;
- A registration scheme for agricultural suppliers be introduced with random inspections, technical information dissemination and training provided;
- A registration scheme for animal manure traders be introduced to assist with monitoring of the supply and distribution system for animal manures and facilitate disease control;
- The Lao PDR Government should investigate the maximum total potential animal manure supply to better understand the constraints of supply on organic vegetable production.
- Adoption of the Clean Agriculture Development Action Plan (Ministry of Planning and Investment 2016) would be assisted by:
  - The facilitation of a price incentive for vegetables produced with Clean Agriculture Certification for the domestic market;
  - The development of levels of Clean Agriculture Certification with less onerous compliance requirements to enable smallholder farmers to participate in the scheme;
  - Short-course training for farmers be expanded to facilitate improved production practices that comply with the Clean Agriculture Certification Scheme.

7.2 Socio-cultural and socio-economic context of smallholder vegetable farmers (Objective 2)

Agriculture is a primary source of income for poor rural people. The livelihoods of smallholder vegetable farmers in Lao PDR and Cambodia were analysed based on a Sustainable Livelihood Framework (Scoones, 2005). The conceptual framework was used to analyse peoples' access to resources (tangible and intangible) for livelihood. The resources include five capitals: natural capital, physical capital, financial capital, human capital and social capital. The approach allows researchers to understand how poor people construct their lives by taking advantage of different opportunities and resources. Using both a participatory approach and the sustainable livelihood framework allowed researchers to identify the community characteristics and issues that might influence adoption of soil and irrigation innovations. Livelihoods analysis was conducted in Lao PDR (Palaniappan et al. (2018) Baseline Livelihood Analysis - Lao PDR_SMCN 2014_088 Technical Report) and Cambodia (Starasts and Tech (2020) ACIAR SMCN 2014 088 Livelihoods and Farming Systems Study).

7.2.1 Cambodia

In Cambodia the baseline livelihoods and farming systems analysis was conducted in January 2017 (Starasts and Tech, 2020) and the key results are summarised here.

Households

In Cambodia, the average family size was 4-5 persons and average age of farmers (male and female) in all villages is approximately 45. Most farming families in the study had both parents working on the farm. The average age of the head of the family is 47 years.

Survey data indicates that vegetable production is a second occupation for most participants across all villages. Twenty two percent of respondents (26) were female who all nominated farming as their main occupation, with 16 of these identifying growing vegetables as their second occupation. As an example of occupations, most participants in the study from Koun Sat village nominated a male household member as head of the household and all except four of these identified farming as their major occupation.

Male and female family members had similar levels of education, except that in both Kampot and Siem Reap Provinces, females had higher attendance at Primary School and in Siem Reap males had a higher level of attendance at Secondary School. No participant family members had university-level qualification. Importantly, approximately 20% in Kampot and on average 36% of Siem Reap participants had not attended school.

Physical capital

The household family's requirements were the main items consumed from vegetable profits. After family assets, the main assets included irrigation equipment which supported field production. Data showed variation across villages with few farmers owning tractors, many using hand watering and many using motor cycles for travel. Many owned cow, pig, chicken and duck livestock assets (for manure).

Hand tractors were used mostly for rice production. Animals and hand methods were used mostly for vegetable production. More participants in all villages (except Prey Ben) used two wheel hand operated tractors to prepare their land for planting; animals are the second most important means of land preparation. More participants from Prey Ben used animals to prepare their land, but similar numbers used hand tractors.

Land - Farmers' ability to grow vegetables especially in the wet season varied depending on their farm elevation and layout. The climate is not suitable to produce vegetables in the wet season in some areas. There are three categories of land use in the project target area for vegetable production. The first category is only rice cultivation and data collected in Siem Reap province indicates that the average land used is around 0.8 ha per household family with two rice ecosystems, wet season and rice ecosystem before flood (where farmer has land for growing short maturity rice in early wet season). In Kampot province the land used for rice production is 0.56 ha per household family on average with only wet season rice ecosystem. In the second category land is used only for vegetable production. In Siem Reap province this area is 0.09 ha per household family on average with two different situations of areas - upland field and lowland field. In upland fields farmers transport soil from elsewhere to fill in, and farming is small scale; in lowland fields farmers have medium sized cultivation areas. In Kampot province there is only small scale vegetable production (0.06 ha per household family on average in the two villages). In the third category, vegetable production after rice harvesting is low capacity in the project area, depending on the rainy season and if the canal-irrigation wter supply is enough for supporting field production during a drought. If the land is very far from the source of irrigation water some areas cannot use the water to grow vegetables. The average land for vegetable production varies from 0.07 ha in Popis to 0.19 ha in Trapeang Chrey.

Irrigation - Villages rely to a large extent on ponds as a source of irrigation water. In Kampot, Trapeang Chrey mostly relies on rainwater as an irrigation source, and to a lesser extent ponds and canals. In Kun Sat, canal water sources are the main source of irrigation water in addition to ponds, and rain and lakes also are significant sources. In Siem Reap, Ta Trav village relies exclusively on water from ponds. In Popis, canals and to a lesser extent wells are also used, but mostly ponds. Most participants relied on diesel pumping to access their water and there was extensive use of irrigation by hand.

Financial capital

Most participants' income was spent on family consumption, study expenses and irrigation equipment. Most farmers used their own sources of finance to support their vegetable production with only a small number borrowing for cropping expenses. Twenty percent of participants from Ta Trav village and 10% of participants from other villages indicated they borrowed money to pay for family consumption and expenses. One third to one half of all participants did not earn any extra income off farm.

Vegetable sales - The 2017 Farming Systems survey identified that farmers sell vegetables directly to collectors in the field supporting other markets in Siem Riep province, and especially restaurant, hotels and supermarkets (including Sammaki, Pouk, Prama markets) in this and other provinces in Cambodia (96.4% participants). The second way of selling vegetables was a small farmers' retailer when harvested – once processed, farmers transfer vegetables to local businesses. Some farmers have contracts or relationships with the trader (around 1.8% participants). In Kampot province, 49.2% of participants sold vegetables to a collector in the field (which were sold on to retailers). Also only a small percentage of farmers had direct business relationships with traders, collectors, or market retailers (1.8%).

Human capital

Participants indicated that they had extensive experience farming with most having over 20 years of farming. In Popis, participants had on average 13 years farming. Most participants reported an interest in farming, with Trapeang Chrey and Popis reporting slightly lower interest. Most participants indicated they were very interested or 'a little' interested in farming. Koun Sat village had six participants indicating 'not interested' in farming. Focus group discussions identified that participants chose to farm to provide income and food as well as support their livestock. Participants highlighted the traditional nature of farming and that they enjoy it and have available time to undertake farming.

On average each household has at least 2 people working on the farm in each village (in Trapeang Chrey there are 3). In all villages each household had at least one member working off farm (in Trapeang Chrey there were 2 members on average working off farm), and at least one member studying (Koun Sat, Ta Trav and Popis had two members studying on average).

Environmental capital

Problems emerged where vegetable farmers faced the incidence of rocks in cropping soils making ploughing difficult and the difficult lay of the land (uplands or lowlands). Sandy soils, especially in Kampot were at risk from erosion during large rain events and did not hold moisture during drought events. Drought was a limitation where irrigation water was scarce. Soil insects were also identified a problem in vegetable production.

Social capital

Approximately 40% of participants had attended farmer training in fertiliser application and irrigation previously (often in rice production). Up to half of participants had participated in farmer groups, others indicating that time was their main limitation for this, but some had not been invited. Many participants indicated they only communicate beyond their family networks occasionally.

7.2.2 Lao PDR

In Lao PDR the baseline livelihoods analysis was conducted in January 2017 (Palaniappan et al. 2018) and the key results are summarised here.

Household demographics

The household survey was conducted in the villages of Huaha (27 households) and Pakxapkao (25 households) in Vientiane Capital and Katouad (31 households) and Thongset (31 households) in Champasak Privince, with 114 respondents in total. Amongst the respondents, 61 were male and 53 were female with higher representation of females in Pakxapkao and higher representation of males in Thongset. Farming experience was 20 years on average, and higher in Thongset and Huaha. The reason for farmers having a longer period of farming experience in Huaha is because vegetables are grown over generations and because the village is located close to Mekong River. The reason for less farming experience in communities in Pakxapkao is because vegetable growing is a recent economic activity and farmers were previously dependent on forest resources. Across villages there was no significant variation in the household size. The number of adults in the household is 2 with 3 children in most sites. The percentage of household heads that hadn't attended school was 8.4%, with 56% attending primary school and 24% attending highschool.

Physical Capital

Households across all sites have electricity and the mobile phone is the most common communication device, with more than 80% of respondents using mobile phones for communication. Women don't own mobile phones in Thongset and Katouad and they consider the phones used by their spouse to be a shared phone for their family. In general, the reliability of the phone service is good. The most common fuel used for cooking is charcoal and wood. The mode of transport commonly used is tricycle. In Thongset and Katouad mini-trucks are also used for transport.

Financial Capital

Savings was referred commonly in all sites as a financial asset followed by cash. Amongst all sites those in Pakxapkao recorded the highest percentage of savings and cash. Gold is commonly seen as non-cash security in all sites. Collectors, in return for their produce, practiced informal lending during harvest. The informal lending and borrowing is commonly followed by farmers for various reasons including sharing of risk, long-term relationship and trust. In terms of irrigation equipment, hoses are most common in Huaha (100%) followed by Pakxapkao (90%), Thongset (68%) and Katouad (20%). Water pumps are most common in Pakxapkao (100%) and Huaha (100%) followed by Thongset (70%) and Katouad (20%). Watering cans are common in Huaha (90%) followed by Pakxapkao (80%), Katouad (78%) and Thongset (60%). Across all sites chicken and duck raising is commonly practised followed by goat. Chicken is raised mainly for rituals such as "Soukhouane" uniting family and community members on occasions such as marriage, new born and other joyful celebrations. Cattle raising is common in all sites other than Katouad. Swine are kept only in Thongset and Katouad. Most of the farmers acquired their land through inheritance and land leasing is not a common practice.

Human Capital

Market price and demand followed by planting season are the major influencing factors to decide crops in all sites. It is evident that across all sites, traditional task division is gradually changing and women are increasingly involved in land preparation and irrigation. Across all sites, farmers needed technical advice in marketing, pest and disease management. Most farmers agreed that they were highly dependent on synthetic pesticides to control pest. Farmers were aware of the health effects of using pesticides and considered them as indispensable inputs. Most farmers in Katouad and Pakxapkao indicated that they monitor their sales as well as the production costs incurred. Most respondents in Pakxapkao are exposed to farm trainings, followed by respondents in Thongset. However, farmers from Thongset have not participated in farm tours. In addition, more females receive training in Huaha and more males receive training in Thongset. The reason for more farm trainings in Pakxapkao was due to the presence of a farmer group engaged in vegetable production called "Kum Phou Phalith Phak". The number of females adopting new farm practices is higher than males in Pakxapkao. In addition, the number of males adopting new farm practices is higher than females in Thongset. Soil preparation methods were trialled by farmers in Pakxapkao and irrigation practices were trialled in Thongset.

Possible health effects from use of chemicals was reported by participants. In Laos, up to 25% of participants (mostly in Champasak) believed there were health risks. Similarly in Cambodia over 60% of participants stated they were suffering from health issues which they believed were due to farming. A majority of farmers in most sites also reported market price and demand as a risk. Less than 40% of respondents across sites admitted that they plan their farm business. Most farmers relied on personal experience, and informal networks (family, friends, and colleagues) to meet their information needs.

Environmental Capital

Among the environment-related activities, the majority of the respondents reported to have cleared land and less than 20% of respondents in Huaha practiced soil erosion management.

Social Capital

Male respondents across sites indicated that they know virtually everyone or most people compared with female respondents. Male respondents across sites indicated to have good communication compared to the female respondents. Female respondents' participation in voluntary activities is recorded to be higher in Pakxapkao than in other sites.

7.2.3 Discussion

Overall, the analyses identified low levels of education and a strong reliance for some on cash flow associated with vegetable production. Poor or no returns were common to approximately one third of farmers. In Cambodia, most farmers sourced information largely from within their family or village and some household members did not often communicate beyond their family networks. Similarly, in Lao PDR most farmers relied on personal experience and informal networks (family, friends, and colleagues) to meet their information needs. Many farmers had attended training and varying percentages were prepared to trial and adopt new technologies (ranging from 4% of women in one village in Lao PDR to over 50% of participants in another village in Cambodia). The studies identified different roles for female farmers including sowing, weeding and post-harvest activities whilst males undertook land preparation and pest and disease management especially in Lao PDR. However, across all sites in Lao PDR, traditional task division is gradually changing, and women are increasingly involved in land preparation and irrigation. The results indicated that both men and women farmers have decision making power on the soil and irrigation management practices to manage their land. The studies identified that farmers lack information on soil management and irrigation practices. In Cambodia many men left the farm to obtain outside employment, leaving females to often manage vegetable production and attend field days. Most farmers used their own money to fund vegetable inputs which potentially is the major limitation for adoption of new strategies. In Lao PDR, some families accessed microfinance to pay for family consumption. In Lao PDR vegetable collectors practised informal lending during harvest, in return for the farmers' produce. Informal lending and borrowing are commonly used by farmers for various reasons including sharing of risk, long-term relationships and trust.

Initial project planning with representatives from Cambodia and Lao PDR as part of Participatory Impact Pathway Analysis group discussions also identified that key problem areas were farmer confidence and knowledge and the availability of information along with poor management of fertiliser and pest and disease strategies. Discussions identified low availability of water for some in dry times. Vegetable farmers in the study areas were operating often as a secondary occupation for the farming family with limited farm labour and often using hand tools. Importantly less than 35% of farmers had any education beyond primary and approximately 20% in Kampot, 36% of Siem Reap participants and 8% of Lao participant household heads had not attended any school. This phase of research concluded that the project extension strategies must align within the socio-economic and socio-cultural context of vegetable farmers and contribute to meeting livelihood needs including reduction of input costs, contributing to higher yields and enhanced profits, conservation of water, contribute to the sustainability of production, improve the health of soils, increase the availability of technical information to farmers, and saving of labour requirements.

7.3 Soil acidity, nutrients and organic matter management (Objective 3)

The effects of mineral and organic fertilisers and lime on vegetable crop yields were studied over three dry seasons at numerous smallholder farm and research sites in Kampot and Siem Reap Provinces in Cambodia and Vientiane Capital and Champasak Provinces in Lao PDR.

7.3.1 Mineral and organic fertilisers and agricultural lime treatments

Commonly available mineral fertilisers were applied in the first season in both countries according to farmer practice. In subsequent years, the project teams tried to mix their own NPK formulations to better match theoretical crop nutrient requirements, and this revealed that appropriate fertiliser blends were not always commercially available. The most commonly available fertilisers are NPK fertiliser and urea, with the NPK ratios commonly used by farmers being 15-15-15, 20-20-20 and 16-8-8.

Optimised NPK ratios and rates for trials in both countries were calculated based on a publication from an institute in Germany specialised in ongoing research on fertiliser requirements of open field vegetable crops commonly grown in the country (http://www.igzev.de/publikationen/IGZ_Duengung_im_Freilandgemuesebau.pdf).

While some of the vegetables grown in Lao PDR and Cambodia are not commonly grown in Western Europe, like morning glory, comparable vegetable types were used to estimate nutrient requirements. Comparability was estimated based on phenotype, plant density and yield expectations. For example, the production system in Lao PDR and Cambodia is significantly different to how lettuce is produced in Western Europe. The varieties and plant density are very different, so the main criteria was yield expectation, and nutrient requirements to achieve a 4 kg/m^2 yield.

Mineral fertiliser was usually applied before planting. On occasions, especially with longer-term crops like broccoli, the fertiliser was split into basal and side dressing application. The side dressing was mostly applied by dissolving the fertiliser in watering cans with the normal irrigation practice or applying the fertiliser with a watering can then using the shower hose to water the fertiliser deeper into the soil.

Lime was also sourced from local suppliers. In Lao PDR, limestone-based agricultural (ag) lime ($CaCO_3$) was used in all lime trials and demonstrations, while a commercially available (though not widely) formulation of burnt lime (40% CaO) was used in Cambodia. In both countries, the ag lime was applied a few days before transplanting and watered in or worked into the soil.

If the farmer commonly applied organic material like cow manure and rice husks, all treatments received the same amount. Plant nutrient inputs from these organic materials were not measured and not accounted for in the NPK fertiliser requirement calculations. The materials for the self-prepared organic fertilisers for the trials in Lao PDR were sourced locally. The prepacked commercial types were sourced from local suppliers. The nutrient content of the organic fertilisers used in the Lao PDR trials can be found in Table 2.

Table 2. Characterisation of organic fertilisers used in Lao PDR trials

Description	pH (1:2.5 H_2O)	OM (%)	N total (%)	P_{avail} (mg/kg)	K_{avail} (mg/kg)	Moisture (%)
Fermented manure (Kathu Luang) compost	6.2	13.32	1.08	212.8	315.3	44
Organic fertiliser (LK organic fertiliser)	6.7	6.67	1.17	0.2 % (total)	0.69 % (total)	31
Cow manure and rice husk (50:50 approximately)	7.2	19.81	1.01	184.5	374.2	44
Chicken manure & rice husk (50:50 approximately)	6.7	NA	3.58	0.42	1.93 % (total)	NA
Chicken manure & rice husk (Farmer, ratio unknown)	6.9	33.6	5.0	0.28	3.6 % (total)	NA
Compost made at HRC from vegetable leaves, grass, cow manure	7.5	12.35	0.60	182.7	322.0	38

7.3.2 Soil analysis

Soil samples from all replicated, and demonstration sites were analysed for pH, EC, macronutrients, CEC and soil texture at two soil depths (0-15 cm, 15-30 cm) in the first year (2016/17). The following year, only new sites in Lao, PDR, had a full suite of soil characterisation done, while in Cambodia only soil pH was measured. Soil pH again was the main focus for the last season in both countries. If soil pH was the only factor that was being measured, the measurements were done in-house in both countries, while for the full suite of soil characterisation soil samples were sent to specialised laboratories. Methods used are listed in Table 3.

Table 3. Methods employed for soil chemical and physical analyses.

Soil Parameter	Analysis Method
pH (H_2O)	1 : 1; 1 : 2.5; 1 : 5
pH (KCl)	1 : 5
EC (H_2O)	1 : 5
Organic Carbon	(Walkey & Black)
Total Nitrogen	(Kjeldahl sulfuric digestion)
Available Phosphorus	Bray II
Cation Exchange Capacity (CEC)	1M Ammonium Acetate at pH=7 & leach with 10% NaCl
Exchangeable Base	1M Ammonium Acetate at pH=7
Exchangeable H	1M KCl
Exchangeable Al	1M KCl
Particle Size Analysis	Pipette (Clay: <0.002 mm; silt: 0.002-0.02 mm; Sand: 0.02-2 mm)

7.3.3 Soil characterisation (structure, NPK, pH, EC, organic matter)

Prior to the application of the experimental treatments, most sites had the expected low soil pH of <5.5 (Table 4-Table 7). All the Cambodian sites were very acidic while some of the soils around Vientiane and the highlands in Champasak in Lao PDR had reasonable pH levels (Table 4, Table 5). Almost all soils had moderate to high phosphorus levels. Only the soils at the research stations in Lao PDR had moderate to high potassium levels while all farm soils in both countries had low or very low levels of plant-available potassium.

Organic matter in the soils of intensive vegetable farms in both countries varied considerably. Land that was used exclusively for vegetable production frequently receives considerable quantities of organic materials often purchased from nearby intensive animal operations (chicken manure), rice mills (rice husks) or from suppliers trading with all sorts of organic waste materials. This practice achieves and maintains organic matter content in these soils at levels of up over 10 % despite frequent soil cultivation and intensive irrigation practice (Table 4, Figure 5). Using the standard conversion factor of 1.72 for the organic carbon data from the soil analyses, the soils used for trials and demonstration in Lao PDR had a range of 0.2 to 10.4 % organic matter content (Reference: Total Organic Carbon, Wayne Pluske, Daniel Murphy, Jessica Sheppard, http://www.soilquality.org.au/factsheets/organic-carbon). In Cambodia the range of organic matter content in the soil that was analysed was 1.4 to 2.7%.

Soil organic matter in the soil from sites in the Lao PDR was well above average, probably due to regular incorporation of rice husk and animal manure. In contrast, the soils in Kampot Province in Cambodia (in particular), which are also used for rice growing, had low to very low levels of organic matter.

Figure 5. Soil condition in Champasak province on farms along the Mekong River. Photographer John McPhee, 10/06/2016

Table 4. Characterisation of soil for sites in Lao PDR, 2016/17

Farmer	Location	Soil depth	Particle Size			Soil class	pH		EC	Org C	Total N	Total P	Total K	P_{avail}	K_{avail}	NH_4	NO_3	Exchangeable Bases				
			Clay	Silt	Sand													Ca	Mg	Na	K	Exch-Al
		(cm)	(%)				(1:2.5 H2O)	(1:2.5 KCl)	mS/cm	(%)				(mg/kg)		ppm		meq/100g				
Farmer 1	Pakxapkao[1)]	0-15	23	29	49	Loam	4.7	4.1	0.05	0.10	1.4	0.09	0.04	21.1	108.1	14.7	7.7	1.77	1.37	0.01	0.29	0.41
		15-30	27	26	48	Sandy clay loam	4.3	3.9	0.05	0.11	1.2	0.08	0.02	1.0	40.6	21.0	5.3	0.57	0.59	0.01	0.11	1.43
Farmer 2	Pakxapkao[1)]	0-15	38	41	22	Clay	4.7	3.9	0.06	0.34	2.3	0.21	0.15	53.3	269.3	18.9	13.0	3.27	4.65	0.03	0.69	0.74
		15-30	50	38	13	Clay	4.5	3.8	0.03	0.39	1.4	0.27	0.10	10.1	78.8	12.3	4.6	2.11	3.04	0.03	0.21	1.82
Farmer 3	Nasala[1)]	0-15	15	40	46	Loam	5.8	5.1	0.06	0.09	1.2	0.08	0.04	11.8	76.2	11.9	3.2	5.44	3.76	0.04	0.20	0.03
		15-30	21	30	50	Loam	5.2	4.5	0.02	0.13	0.8	0.07	0.03	4.3	72.6	8.8	3.9	3.86	3.29	0.05	0.19	0.49
Farmer 4	Huaha[1)]	0-15	24	57	20	Silty loam	7.9	7.2	0.11	0.36	0.7	0.07	0.11	32.8	24.8	11.9	3.3	14.77	6.26	0.13	0.07	0.04
		15-30	27	59	15	Silty loam	7.9	7.2	0.09	0.36	0.7	0.08	0.08	25.4	49.8	4.6	2.5	12.79	6.05	0.20	0.13	0.03
Farmer 5	Huaha[1)]	0-15	17	57	26	Silty loam	7.9	7.3	0.10	0.34	0.8	0.07	0.10	53.6	43.2	21.8	6.3	11.25	1.93	0.08	0.11	0.04
		15-30	20	53	26	Silty loam	8.2	7.3	0.05	0.35	0.4	0.04	0.08	17.6	10.2	8.1	3.9	11.89	3.09	0.12	0.03	0.02
Farmer 6	Thongset[2)]	0-15	64	26	10	Sandy loam	4.7	4.6	0.06	6.07	0.40	0.21	1.81	0.08	46.14	26.25	0.18	1.10	1.28	0.01	0.12	0.12
		15-30	54	31	15	Sandy loam	4.7	4.6	0.04	4.76	0.26	0.17	0.45	0.07	17.11	19.60	0.16	0.43	0.57	0.01	0.04	0.10
Farmer 7	Donley[2)]	0-15	31	52	17	Silty loam	4.9	4.3	0.05	2.82	0.17	0.17	73.54	0.28	119.16	13.30	0.13	5.88	6.63	0.09	0.31	0.08
		15-30	24	56	20	Silty loam	5.4	4.7	0.04	1.44	0.08	0.11	46.82	0.33	33.04	6.65	0.08	7.54	6.36	0.10	0.09	0.03
Farmer 8	Nongbua[2)]	0-15	42	37	21	Loam	5.1	4.5	0.11	2.19	0.11	0.13	57.39	0.12	107.92	18.55	0.22	3.19	4.82	0.19	0.28	0.05
		15-30	39	35	26	Loam	5.1	4.9	0.07	0.65	0.07	0.04	15.83	0.13	69.89	6.30	0.08	2.59	3.20	0.16	0.18	0.87

[1)] Vientiane Province

[2)] Champasak Province

Table 5. Characterisation of soil at NUOL research station, Vientiane, Lao PDR, used for replicated trials in 2017/18 and 2018/19

SOIL DEPTH	Particle Size			pH (1:5 H_2O)	pH (1:5 KCl)	EC (1:5)	OM	Total N	P_{avail}	K_{avail}	P total	K total	Exchangeable Bases				Exch-Al
	Clay	Silt	Sand										Ca	Mg	Na	K	
(cm)	(%)					dS/cm	(%)		(mg/kg)		(%)		meq/100g				
0-15	24	21	55	4.89	3.92	0.36	6.34	0.15	120.8	195.5	0.37	0.39	2.98	1.39	0.25	0.50	0.62
15-30	30	20	50	4.55	3.76	0.22	2.66	0.13	16.1	94.8	0.08	0.46	1.70	0.93	0.22	0.24	2.46

Table 6. Characterisation of soil from sites in Cambodia used in the season 2016/17

Location	SOIL DEPTH	Particle Size			pH (1:5 H_2O)	pH (1:5 KCl)	EC (1:5)	Org C	Total N	P_{avail}	CEC	Exchangeable Bases				Exc-H	Exch-Al
		Clay	Silt	Sand								Ca	Mg	Na	K		
	(cm)	(%)					dS/cm	(%)		(mg/kg)	meq/100g						
Popis village, Krobey Riel commune, Siem Reap city, Siem Reap province	0-15	1	7	92	6.0	5.2	0.36	1.56	0.14	460.00	8.50	2.70	1.30	0.13	1.15	1.00	0.60
	15-30	5	11	84	5.9	5.1	0.38	1.16	0.11	560.00	9.50	3.20	1.20	0.10	1.82	1.00	0.50
	30-60	6	11	83	6.2	5.8	0.40	1.09	0.11	740.00	9.00	2.50	1.30	0.07	0.68	1.50	0.80
Kantrang village, Ta Trav commune, Prasat Bakorng district, Siem Reap province	0-15	3	9	88	6.4	5.8	0.27	1.37	0.14	480.00	8.50	2.40	1.00	0.07	2.10	2.50	1.00
	15-30	5	11	84	6.2	5.7	0.20	1.58	0.14	370.00	7.50	2.60	1.20	0.05	0.55	3.00	1.15
	30-60	1	9	90	6.6	5.7	0.23	1.09	0.11	78.00	6.50	2.80	1.20	0.05	0.33	3.00	1.05
Koun Sat village, Koun Sat commune, Teuk Chou district, Kampot province	0-15	7	25	68	5.9	5.3	0.08	0.84	0.07	47.00	8.00	2.90	1.10	0.08	0.23	5.50	1.50
	15-30	9	20	71	6.0	5.0	0.05	1.13	0.11	30.00	8.50	2.70	1.00	0.07	0.14	1.50	0.55
	30-60	8	17	75	6.2	5.0	0.04	1.14	0.11	25.00	7.00	2.50	1.20	0.07	0.13	2.00	0.90
Trapeang Chrey village, Chhouk commune, Chhouk district, Kampot province	0-15	4	21	75	6.0	5.0	0.09	1.04	0.11	104.00	7.50	2.40	1.30	0.09	0.40	2.50	0.65
	15-30	4	25	71	6.1	4.8	0.04	0.88	0.07	50.00	8.50	2.60	1.20	0.10	0.55	3.50	0.75
	30-60	18	33	49	5.8	4.2	0.06	0.82	0.07	26.00	10.00	2.70	1.10	0.04	0.19	4.00	1.50

Table 7. Soil pH before planting, Kampot province, Cambodia 2017/18

Location	Soil Depth (cm)	pH (1:1 H_2O)	pH (1:5 KCl)	EC (1:5) (dS/cm)
Koun Sat Village, Koun Sat Commune, Kampot	0 - 15	5.9	5.3	0.08
	15 - 30	6.0	5.0	0.05
	30 - 60	6.2	5.0	0.04
Trapeang Chrey Village, Chhouk Commune, Kampot	0 - 15	6.0	5.0	0.09
	15 - 30	6.1	4.8	0.04
	30 - 60	5.8	4.2	0.06

7.3.4 Soil pH and the effect of agricultural lime on the yield of leafy vegetables

The strategy in Lao PDR for trials and demonstration to test the effect of agricultural (ag) lime on soil pH and crop performance was to add sufficient lime to raise soil pH by 0.5 or 1.0 units. As most soils in the project were classified as loam and silty loam, this equated to about 2 t/ha and 4 t/ha, respectively, of limestone material.

The replicated experiment at the research station of the agricultural faculty of NUOL in the season 2017/18 received these treatments, and the effect on soil pH is presented in Table 8. The pH after harvest measured only marginally higher than before application of the two rates of ag lime. Interestingly, the pH (KCl) values improved in an obvious way, which can be taken as an indication that the applied lime effectively reduced acidity for the plant roots.

Table 8. Soil pH before planting and after a lettuce crop after treatment with different rates of limestone (NUOL irrigation trial 2017/18

	Before planting		After harvesting		
			No lime	2 t/ha	4 t/ha
	0 -15 cm	15- 30 cm	0 -15 cm		
pH (H_2O)	4.9	4.6	4.7	5.0	5.3
pH (KCl)	3.9	3.8	4.1	4.4	4.9

While ground cover and number of leaves per plant presented no clear trend of the effect of lime on plant growth (Figure 6), the yield clearly improved (Figure 7). The high variability between replications is presented in the error bars. The total yield is about half of what can be achieved by some farmers. The less than 100% ground cover at 28 days after transplanting (just before harvest) suggests that plant density was well below commercial practices. Additionally, the lime was applied four days before planting. The effect of lime could potentially be improved by applying it approximately six weeks before planting.

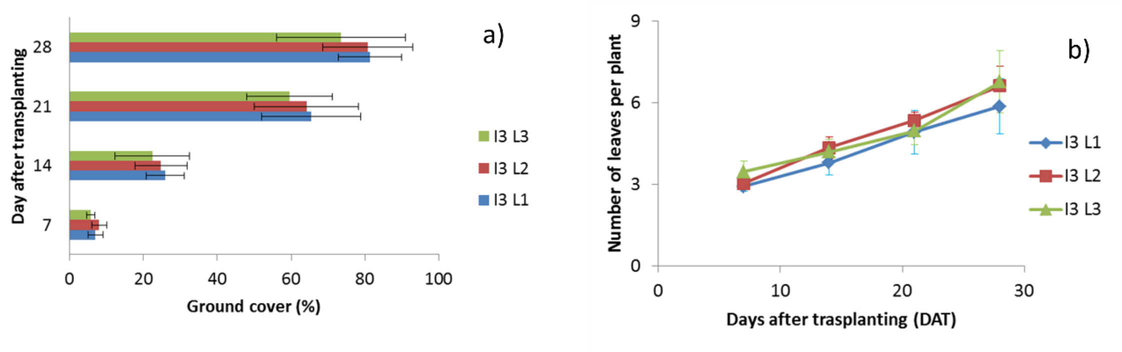


Figure 6. Development of a) ground cover and b) number of leaves per plant of lettuce at 3 different rates of ag lime (L1=no lime, L2=2t/ha, L3=4t/ha; I3=irrigation treatment)

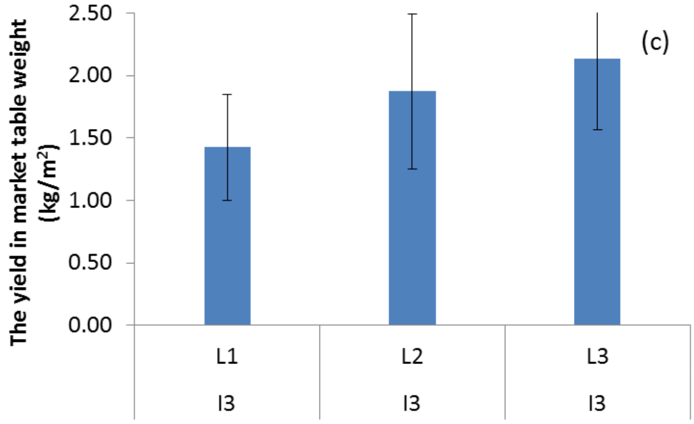


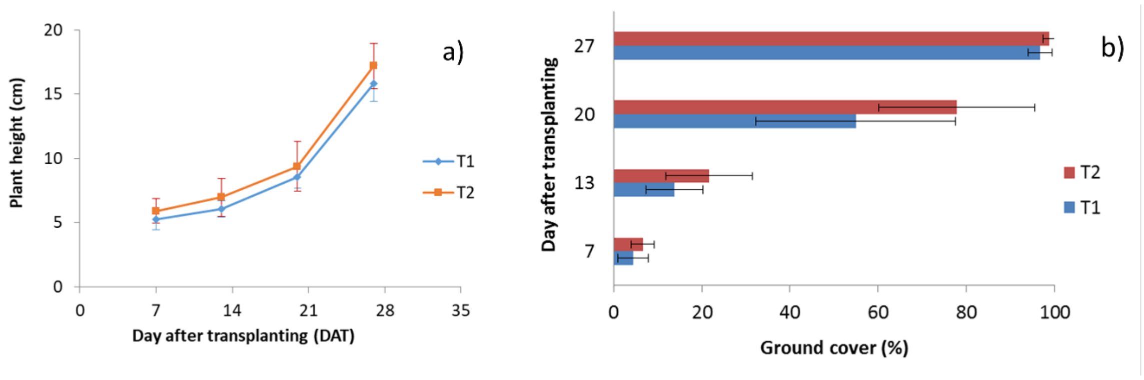
Figure 7. Yield of lettuce with different rates of lime (L1=no lime, L2=2t/ha, L3=4t/ha; I3=irrigation treatment)

A replicated trial with lettuce at a farmer site in 2017/18 showed a similar trend, with yield improvements after applying a rate of ag lime aimed at increasing soil pH by 0.5 units which equated to 2 t/ha. The effect on soil pH after the crop was harvested is presented in Table 9. The application of limestone had a marginal impact of the measured acidity of the soil.

The crop development in both treatments (T1: no lime, T2: 2 t/ha lime) followed similar trends, and the difference between the treatments was not significant (Figure 8). However, a clear trend toward improved yield after applying ag lime was observed (Figure 9). Observed yields of around 1.5 kg/m^2 at this farm are well below what other farmers can achieve (up to 4 kg/m^2). It can be assumed that other factors besides low pH limited productivity at this site.

Table 9. Soil pH before and after application of 2 t/ha of ag lime

	Before planting		After harvest	
			No lime	2 t/ha lime
	0 – 15 cm	15 – 30 cm	0 – 15 cm	
pH (H_2O)	5.0	4.5	4.7	5.0
pH (KCl)	4.2	3.7	4.2	4.2



T1: farmer practice – no ag lime; T2: 2 t/ha ag lime

Figure 8. Development of a) crop height and b) ground cover after transplanting

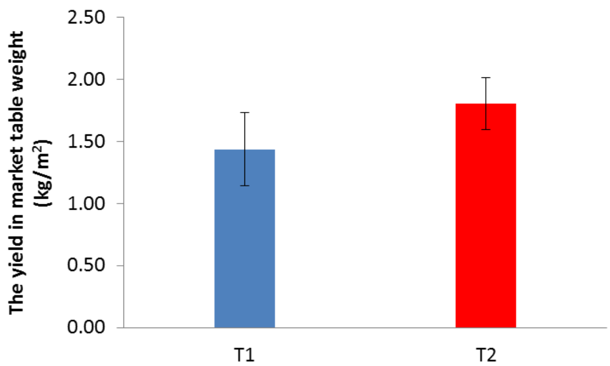


Figure 9. Yield of lettuce 28 days after transplanting. T1: no lime, T2: 2 t/ha lime

The application of lime to raise the soil pH by 0.5 to around 5.0 (H20) had some positive effect on marketable yield and other yield related plant parameters, though the increase was not statistically significant. Of concern is the high application rate of chemical fertilisers (NPK). Even the farmer reported probable fertiliser burn on some of the plants. The application of lime only days before transplanting could have caused local alkalinity shocks, though the application rate of 2t/ha or 200 g/m^2 can be considered possible for clay loams. The timing is more critical. Since the soil pH was only raised to around 5.0 (H_2O) the yield response, while positive, was still limited by the acidic soil conditions. The demonstration was conducted at the end of the dry season with rain already occurring quite frequently which resulted in poor crop health (the crop couldn't be sold due to poor quality) which potentially affected the results.

The assumption that factors other than soil acidity were limiting productivity at this site was tentatively confirmed in the following season when not only lime was added as a treatment but also an NPK treatment based on crop demand. Adding ag lime at a reduced rate of 1 t/ha had limited impact on the pH of the soil as measured after harvest (Table 10). This was a demonstration site with no replications.

Table 10. Soil pH before and after application of 2 t/ha of ag lime

	Before planting	After harvest			
		No lime	2 t/ha lime	No lime + optimised NPK	2 t/ha lime + optimised NPK
	0 – 15 cm	0 – 15 cm			
pH (H_2O)	5.2	4.7	4.7	4.7	5.0
pH (KCl)	4.7	4.0	3.9	4.1	4.2

When the farmer only applies nitrogen in form of urea, a crop-specific NPK ratio and amount based on yield expectations produced a strong trend of improved plant density through a higher number of established plants per square metre (Figure 10). A higher number of established plants then translated well into higher yield at harvest with almost double the yield per square metre for the treatment receiving 1 t/ha lime and an optimised NPK supply (Figure 11).

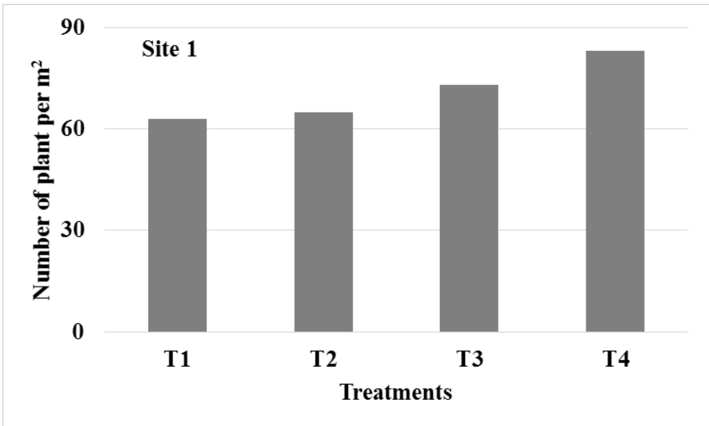


Figure 10. Plant density as influenced by lime and optimised NPK fertilisation. T1: urea, no lime; T2: urea + 1 t/ha lime; T3: NPK, no lime; T4: NPK + 1 t/ha lime

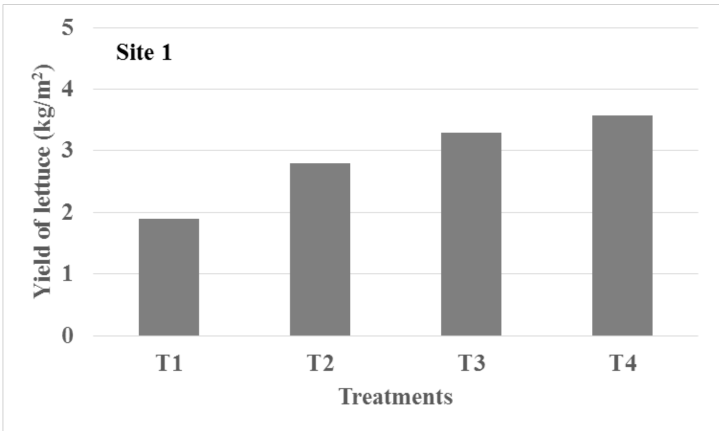


Figure 11. Yield of lettuce 4 weeks after transplanting. T1: urea, no lime; T2: urea + 1 t/ha lime; T3: NPK, no lime; T4: NPK + 1 t/ha lime

If the farmer is already using a more balanced fertiliser regime, yields are already higher. Introducing small application rates of lime and optimised NPK ratios and rates are then expected to have limited impact. While the plant density can be improved with a lime application (Figure 12), the overall yield increases only marginally (Figure 13), since farmer practice already achieves a very good yield. Again, this was a non-replicated demonstration.

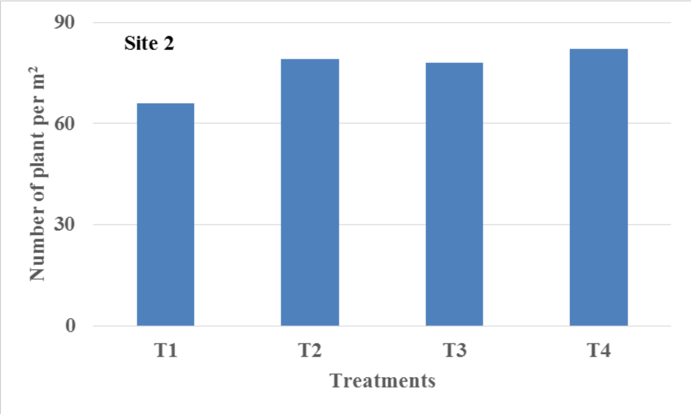


Figure 12. Plant density as influenced by lime and optimised NPK fertilisation. T1: urea, no lime; T2: urea + 1 t/ha lime; T3: NPK, no lime; T4: NPK + 1 t/ha lime

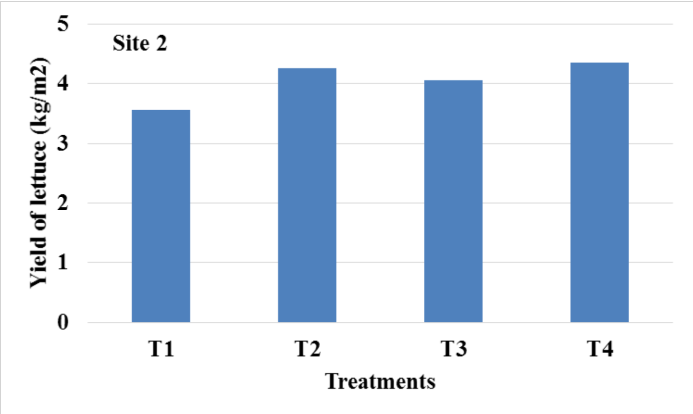


Figure 13. Yield of lettuce 4 weeks after transplanting. T1: urea, no lime; T2: urea + 1 t/ha lime; T3: NPK, no lime; T4: NPK + 1 t/ha lime

Cambodia

In Cambodia, the main focus of the work in the second and third season was demonstrating the effect of managing soil acidity through controlled application of lime. Calcium oxide (40%) was sourced from MaliSan Group as it comes in a granulated form which makes handling easier than the powdery formulation in which Limestone products are available. The mindset for extension messages was different from Lao PDR, with a focus on lime rates and the minimisation of them, compared to achieving the desired change in soil pH in Lao PDR. In Cambodia a large number of the unreplicated demonstration was set up with three different rates of lime (0.5 t/ha, 1 t/ha and 2 t/ha) and a second crop was planted to test and demonstrate the residual effect of lime. This then would inform which of the two extension messages should be promoted: a) small amounts of lime to every crop or, b) larger amount of lime once at the beginning of the season.

The data doesn’t show a clear trend, which was to be expected. One of the problems with the one larger application at the beginning of the season is that if it is based on a standard recommendation, it could lead to an excessive increase in soil pH for the first crop on soils with a high sand fraction. Without proper soil pH testing this strategy has the potential for failure. Data from most demonstrations showed that small amounts of lime applied will improve yields but often might not achieve the higher yields achieved with higher lime rates. But, the effect of these small lime rates on soil pH is limited, hence it can be assumed that the risk of crop damage due to a temporary spike in soil pH is extremely low. Under this scenario, soil pH testing would not be required in the short- and medium-term, which would simplify the extension message and support required for farmers. Data suggests that the lower increase in yield from lower lime rates is always sufficient to cover the costs of the lime applied.

Siem Reap

In the year 2017/18 a number of farm sites in Siem Reap had two consecutive crops to estimate the residual effect of lime. At all sites, but one, soil pH after the crop was higher when lime was applied before planting. The expected trend that soil pH would be higher when more lime was used can be seen in Figure 14. With 2 t/ha of lime applied, the soil pH at this sites, exept one, rose well above 6. A second crop without any extra lime applied didn't change this relationship, although a minor trend of decreasing soil pH could be taken from the data. However, these are non-replicated demonstrations site; these small differences could be random.

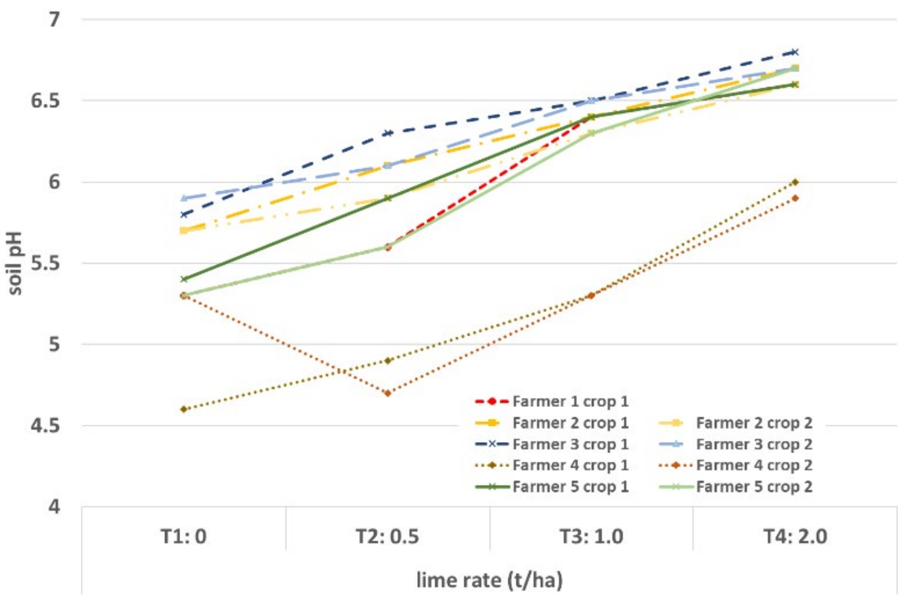


Figure 14. Soil pH as affected by different rates of ag lime after harvest of crop

The effect on yield of leafy vegetables, even when soil pH is already close to 6 (Figure 15) was that by raising the soil pH above 6 but to less than 7 mostly improved the performance of bok choy. While low rates of lime (0.5 t/ha) showed no obvious improvement, the higher rates (1 t/ha and 2 t/ha) raised the soil pH above 6.5, which seemed to have a positive impact on the following crop as well. When lime is applied to soils with a pH of below 5 the effect of initially higher application rates can be quite dramatic (Figure 16), with yield improvements of up to 100%.

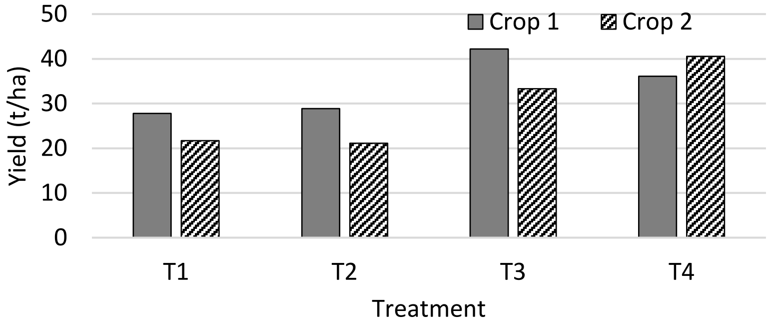


Figure 15. Effect of lime rates on the yield of bok choy at farmer 3 with initial soil pH of 5.9

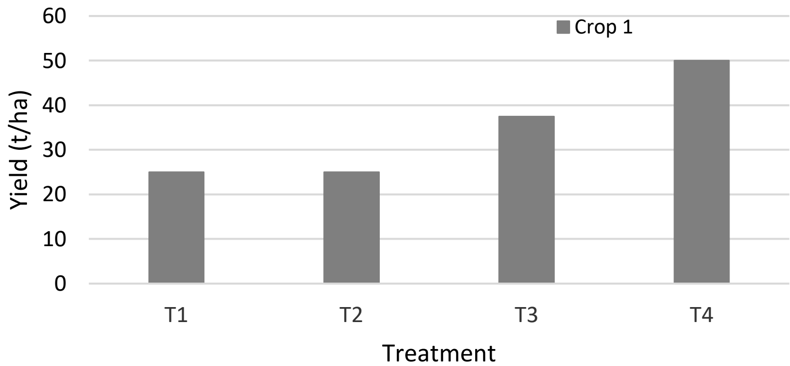


Figure 16. Effect of lime rates on leaf yield of Bok choy at farmer 4 with an initial soil pH of 4.5

The focus in the season 2018/19 in Cambodia was split between different lime rates and lime/NPK demonstrations. To simplify matters even further, farmers in Siem Reap province only grew bok choy, while in Kampot province they grew mustard green. Higher rates of up to 2 t/ha of lime again raised soil pH in both provinces above 6.5 and in some cases above 7 (Figure 17).

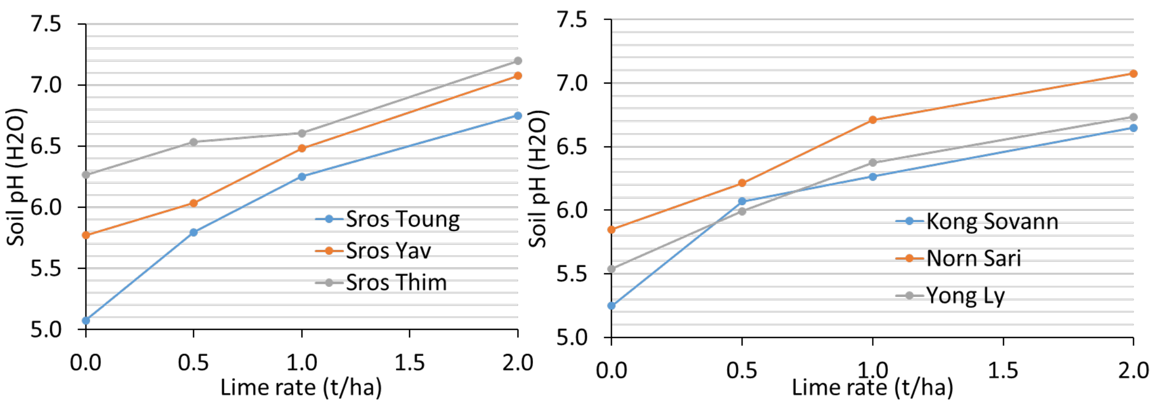


Figure 17. Effect of lime on soil pH: Kampot (left) and Siem Reap (right)

The effect on the yield on the two different crops,presented as the average of crops from three different farms, shows that bok choy responded very well to increased soil pH (Figure 18). Mustard green, on the other hand, while still responding positively to an increased soil pH up to around 6.5, might not benefit from raising soil pH any further and even respond with a decline in yield.

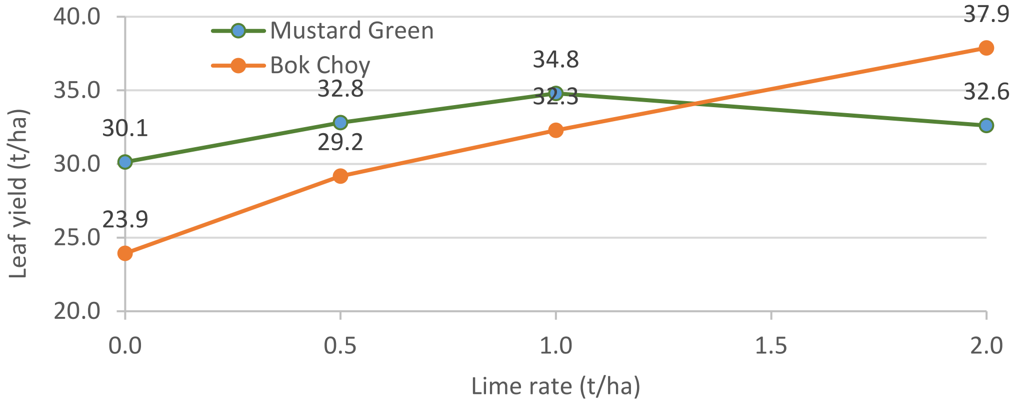


Figure 18. Effect of lime on the yield of mustard green (Kampot) and bok choy (Siem Reap). Data are means of three sites for each crop.

7.3.5 Fertiliser

Farmers in both countries often reported the lack of information on how much fertiliser to apply to their crops. Their main source of information are family and other farmers. The result is completely random fertiliser strategies, which have no relationship to soil type, crop and yield expectation, while the impact on the environment and farm income can be significant. A few examples for Lao PDR are listed in Table 11. The data suggests that most farming practices use urea as the main type of fertiliser, probably for cost reasons. Phosphorus and K, while applied by most farmers, commonly replaces only a fraction of the nutrients removed from the field through the harvest. ‘Farmer 6’ refers to a replicated trial at one of the research farms, and while declared “farmer practice”, the high application rates are probably not representative of practices in the wider farming community.

Table 11. Observed rates of mineral fertiliser and compost applied by farmers in Lao PDR in trials and demonstrations 2017-19

	Inorganic fertiliser (kg/ha)			Organic fertiliser (kg/ha)
Site No.	**N**	**P_2O_5**	**K_2O**	**Compost**
Farmer 1	158	20	32	NA
Farmer 2	101	-	-	NA
Farmer 3	24	12	12	NA
Farmer 4	48	24	24	NA
Farmer 5	77	77	77	NA
Farmer 6	1,110	555	555	8,680
Farmer 7	67	33	33	
Farmer 8	341	84	84	6,000
Farmer 9	150	4	4	3,300

The data from Cambodia paints a very different picture for the fertiliser usage by farmers. A large amount of NPK fertiliser is used, in most cases well above crop demand (Table 12). Urea is probably used to maintain nitrate levels in the soil throughout the crop cycle. Farmers in Kampot Province added large amounts of organic materials, whereas most farmers in Siem Reap don’t seem to maintain the soil organic matter content of their soil.

Table 12. Observed rates of mineral fertiliser and compost applied by farmers in Cambodia in trials and demonstrations 2017-19

	Inorganic fertiliser (kg/ha)			Organic fertiliser (kg/ha)	
Site No.	**N**	**P_2O_5**	**K_2O**	**Compost**	**Clay**
Farmer 1 (KP)	467	467	350	25,000	16,667
Farmer 2 (KP)	250	250	188	12,500	8,333
Farmer 3 crop 1 (KP)	398	283	213	16,667	-
Crop 2	197	158	119	25,000	-
Farmer 4 crop 1 (KP)	858	667	500	55,667	-
Crop 2	173	125	94	50,000	-
Farmer 5 (KP)	533	533	533	2,653	-
Farmer 6 (SR)	269	119	101	-	-
Farmer 7 (SR)	453	150	150	-	-
Farmer 8 (SR)	420	133	133	-	-
Farmer 9 (SR)	528	188	188	-	-

(KP) Kampot Province; (SR): Seam Reap Province

7.3.6 NPK fertiliser usage

A good example of the effect of a balanced NPK ratio and rates adjusted to crop demand is presented in Figure 19 from a non-replicated demonstration site in Lao PDR. Probably for cost reasons the farmer used very little NPK fertiliser. The yield was very low. Increasing the rate of nitrogen being added only improved yield marginally. Adjusting P and K had the biggest impact on the yield of broccoli. The sulphur in the added fertiliser components could have had contributed to the impressive increase in yield, as brassica crops respond very well, if natural supplies are limited.

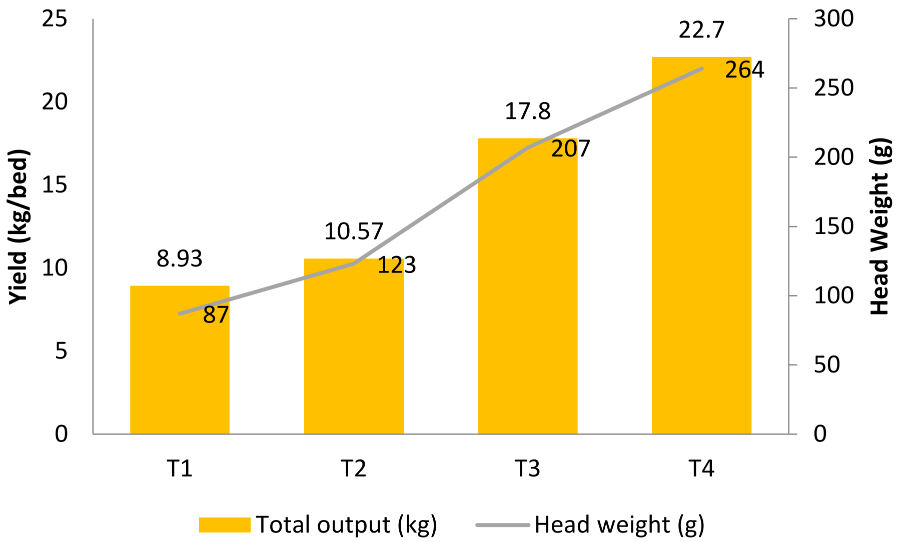


Figure 19. Yield and weight of flowers of broccoli when changing the rate and ratio of NPK fertiliser. T1: N: 24 kg/ha, P2O5: 12 kg/ha, K2O: 12 kg/ha; (farmer practice NPK 16-8-8), T2: N: 260 kg/ha, P2O5: 130 kg/ha, K2O: 130 kg/ha; (optimised for N as NPK 16-8-8), T3: N: 260 kg/ha, P2O5: 130 kg/ha, K2O: 322 kg/ha; (optimised for N and K as NPK 16-8-8 + K2SO4), T4: N: 260 kg/ha, P2O5: 108 kg/ha, K2O: 322 kg/ha; (optimised for N, P and K as single component fertiliser mix)

In Cambodia, the main aim was to demonstrate that a properly balanced ratio of NPK fertiliser is sufficient to maintain yields and that farmers can safely reduce their fertiliser inputs. The data from the season 2018/19, while from non-replicated demonstration sites, support this aim (Figure 20). Yields were maintained when reducing NPK rates to what was estimated to be crop requirements, compared to what farmers apply (FFP=farmer fertiliser practice). Applying lime to raise soil pH had an obviously positive impact on yields (T2 & T4).

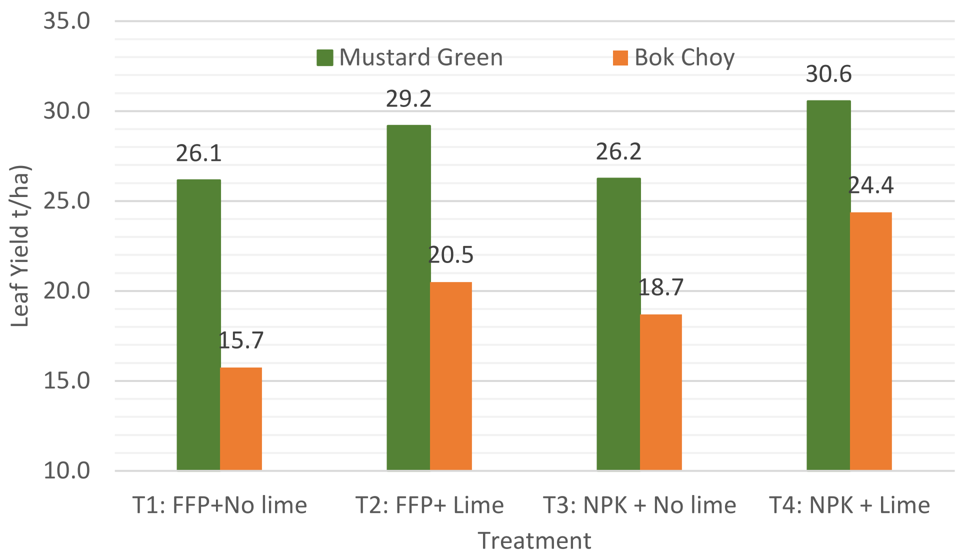
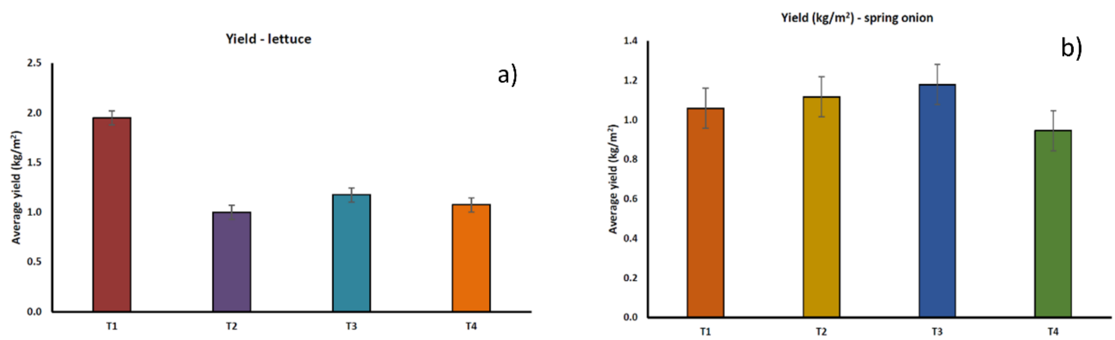


Figure 20. Yield response of mustard green and bok choy to NPK and Lime application. Data are mean of three sites for mustard green, and two sites for bok choy

7.3.7 Organic fertiliser

Replacing mineral fertiliser with organic materials is aspired to by many farmers in Lao PDR, mostly to reduce costs of inputs.

A variety of commercially available organic fertilisers are available in Lao PDR, with the majority coming from Thailand. Farmers frequently produce their own compost by mixing animal manure with rice husk or use organic waste materials collected on the farm. Replicated trials to test the performance of different types of organic fertilisers/composts were inconclusive (Figure 21 a & b). For short term crops like lettuce (30-35 days), a well processed and stable compost might perform better than the composts prepared on the farm (Figure 21 a).



T1 & T2 commercial compost, T3 manure/rice husk mix; T4 compost from farm material prepared at HRC

Figure 21. Yield of lettuce and spring onions as affected by different types and brands of compost

For crops that are in the ground for longer, like spring onions, the degree of processing and ageing of the compost had no significant effect on crop performance, with all types of organic fertiliser achieving similar yields.

Applying higher rates of compost (50:50 cow manure and burned rice husks) to lift the yield potential of the crop did not meet expectations (Table 13). Rice husks have a very low fertiliser value particularly if a large proportion has been converted to charcoal. The age of the cow manure was also not monitored. Both could have had an impact on the rate of nutrients being released. The effect of charcoal potentially absorbing nutrients when they get released from the manure could be a driver here.

Table 13. Effect of different rates of compost on the yield of spring onions. Letters that differ within columns denote statistically significant differences (*P*<0.05).

Rate of Compost	Plant height (cm)	Leaf width (cm)	Length of leaf (cm)	Plant Weight (g)	Yield (kg/m^2)
No compost	25.9 B	0.43 A	22.6 A	40.5 A	1.3 B
5 t/ha	27.9 A	0.46 A	24.3 A	42.2 A	1.6 A
10 t/ha	27.5 A	0.46 A	24.3 A	51.6 A	1.7 A
15 t/ha	27.4 A	0.43 A	24.1 A	50.5 A	1.7 A
F-test	*	ns	ns	ns	**
CV %	2.72	6.51	4.91	25.97	7.16

7.3.8 Economic and environmental impact

For some of the demonstration sites in Lao PDR and Cambodia, an economic assessment was done to show the effect that soil pH management with ag lime and optimised NPK fertilisation can have on profits from vegetable production. One extreme case from Paksong in Lao PDR is presented in Figure 22. The farmer applied a very low rate of fertiliser on their broccoli crop, which limited the yield in a way that the revenue was not enough to cover the costs of establishing and managing the crop. The farmer made a small loss (T1). Investing in more fertiliser increased the cost of production only marginally, but through the improvement of the yield, a small profit was achieved (T2). Using a balanced NPK ratio as fertiliser and with rates aimed at meeting crop demand at higher yields, the yield per bed doubled and the extra revenue was more than enough to cover the extra fertiliser used in these treatments (T3 and T4). These two treatments were able to contribute to the family income in a meaningful way.

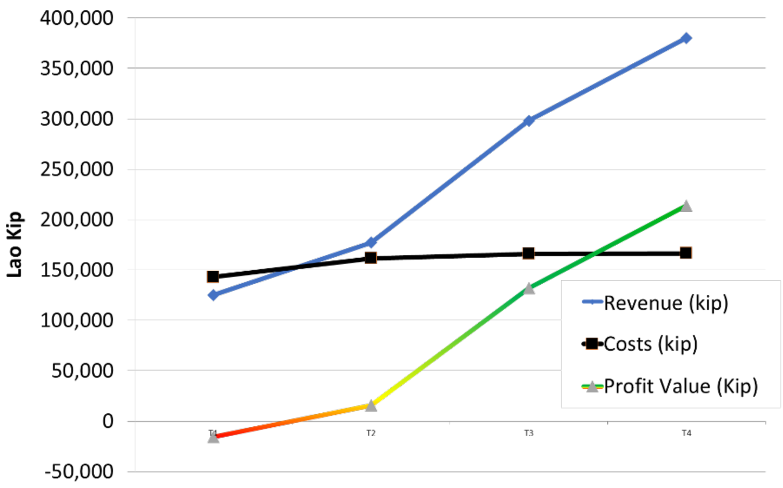


Figure 22. Revenue, costs and profit (before salaries) of improved soil fertility management by utilising a balanced NPK fertiliser T1: N: 24 kg/ha, P_2O_5: 12 kg/ha, K_2O: 12 kg/ha; (farmer practice NPK 16-8-8), T2: N: 260 kg/ha, P_2O_5: 130 kg/ha, K_2O: 130 kg/ha; (optimised for N as NPK 16-8-8), T3: N: 260 kg/ha, P_2O_5: 130 kg/ha, K_2O: 322 kg/ha; (optimised for N and K as NPK 16-8-8 + K_2SO_4), T4: N: 260 kg/ha, P_2O_5: 108 kg/ha, K_2O: 322 kg/ha; (optimised for N, P and K as single component fertiliser mix)

Another impressive example on the effect of lime on the profitability of bok choy in Siem Reap Province, Cambodia, through soil pH management is presented in Table 14. Traditional farming practice costs the farmer US$ 2800 to grow 1 ha of bok choy. Because the yield in this demonstration was reasonably good, the farmer achieved a reasonable profit of just under US $10000 per hectare. Using different rates of ag lime will increase the cost of production by US $300-1200/ha. At the same time, the improved yield from applying lime increases revenue by US $1700-7550/ha, which easily covers the extra expense for the lime.

While these are two extreme examples, where yields and revenue increased dramatically, in almost all demonstration and replicated trials, the same trend was observed.

Table 14. Costs and profit of improved soil fertility management by utilising ag lime to increase soil pH. Monetary values are USD.

Treatments	Lime rate (t/ha)	Fertiliser rate (kg/ha)	Yield (t/ha)	Price vegetable ($/kg)	Input cost			Total input cost ($/ha)	Total income ($/ha)	Profit ($/ha)
					Labour/ materials ($/ha)	Lime ($/ha)	Fertiliser ($/ha)			
L1	0.0	1,416	24.9	0.50	1,866	-	935	2,801	12,450	9,649
L2	0.5	1,416	28.3			300	935	3,101	14,150	11,049
L3	1.0	1,416	35.3			600	935	3,401	17,650	14,249
L4	2.0	1,416	40.0			1,200	935	4,001	20,000	15,999

A basic calculation of estimated potential savings in fertiliser across the vegetable industry in Cambodia based on the data from the demonstrations sites is presented in Table 15. Starasts and Tech (2020) found that fertiliser rates applied by surveyed farmers were lower than were applied as farmer practice in the demonstration trials, so the estimates below may be optimistic.

Table 15. Average saving of nutrients if farmers use optimised NPK application rates (per crop)

	N	P_2O_5	K_2O
	kg/ha		
Kampot	210	260	50
Siem Reap	220	50	-100

In 2019 vegetables were grown on an estimated 58,000 ha in Cambodia. If all the area was planted with similar crops as the ones in the project and if it is assumed that farmers on average would grow 3 crops per season, the industry would save 37,410 t of nitrogen (81,330 t of urea or US$ 17.5m spot price); 26,970 t of P_2O_5 (300,000 t of superphosphate or US$ 30.2m spot price). The use of potassium would need to increase by 4350 t of potassium (10,900 t of potassium sulphate or US$ 4.2m).

The monetary value of the savings would be in the order of US$ 43.4m. Spot prices are about 100-200% lower than farm gate prices. Taking this into account, the savings for farmers in the industry could be well over US$ 100m per season.

As well as reduced fertiliser inputs overall, improved fertiliser and lime management offers substantial environmental benefits. Better matching fertiliser inputs to plant demands, and enhancing nutrient availability through better management of soil acidity reduces the potential for nutrient leaching (and associated soil acidification), runoff (and associated eutrophication potential in receiving waters) and denitrification in waterlogged soils (and associated greenhouse gas emission).

7.3.9 X-project extension tools

When it became apparent that the usage of ag-lime even in small quantities and optimised NPK fertiliser had such huge effect on quality and yield of leafy vegetables in Cambodia, almost immediately the need became obvious to not only inform farmers about the finding but to provide them and their advisors with tools to eventually build an extension program around actively managing soil acidity to sustain the momentum from this project.

The SMCN 2014/088 collaborated with the SMCN 2016/237 project which aimed to test and characterise upland soils for crop intensification. While upland soils rarely present problems with acidity because of their short cropping history, it is vital to avoid this problem through early intervention. This X-project activity aimed to add value to both projects through collaboration over a 12-month period.

With highly variable soil texture and conditions, generalised recommendations of application rates for ag lime can be problematic, as an increase in soil pH above optimum levels causes a similar set of negative effects on plant growth as low soil pH. However, overapplication of NPK usually only causes higher input costs.. Rapid on-farm soil testing could help raise farmer awareness of lime and fertiliser requirements. Many farmers have smartphones, so apps that help interpret soil tests could also help provide recommendations to researchers, extension agents and farmers on lime and fertiliser application.

This project addressed the following research questions:

- Can field soil test kits be purchased, maintained and used to provide advice to farmers on pH and nutrient levels?
- How can a smartphone app be developed and used to provide lime application recommendations to farmers and their advisors?

Soil testing has to be very affordable for farmers to get their involvement. Hobby gardener soil test kits, commercially available in Australia and on ebay internationally are attractive from a cost perspective and mostly use a simple system, where the test results for nitrate, potassium and phosphorus are presented in qualitative units that are easily understood. While laboratory testing showed that the test results are reasonably accurate most of the time, the real concern was the lack of repeatability, which rendered the test results as random. It was concluded that despite their low costs, these kits were unsuitable for use in farming.

As a significant step up, in costs, accuracy and reliability are ion selective meters, which provide results in parts per million or mg/L or in the case of soil pH in numbers with up to 2 decimals. It is a challenge even for extension staff to work out how much kg/ha of urea to recommend when the meter reading is 75 ppm or how much lime to apply when the measured pH is 4.7.

Several internet and app store searches revealed only a small number of online apps which had a strong regional component (type of lime) and terminology while no app for smartphones was available. Hence a simple smartphone app was developed (Figure 23) to allow extension staff, advisers and potentially farmers to easily calculate the application rate of lime depending on soil pH, soil texture, organic matter content and type of lime.

The algorithm used was (Harding, 2016):

((target pH - current pH) * Soil Type Factor)/(Lime Type Neutralising Value * Lime Quality) * organic matter factor

where:

Current pH: estimated or measured value (default: pH 5)

Target pH: Default pH 6

Soil type factor: standard soil texture range from sand to loam

Lime Type Neutralising Value: type of lime and its associated neutralising value

Lime Quality: concentration of CaO or $CaCO_3$

Organic matter factor: a rough estimate of the amount of organic matter in the soil, determined from the rate of organic material the farmers usually apply.

The smartphone app was developed locally in Phnom Penh under the supervision of Dr Sarith Hin from CARDI and is now available for Android phones on Google Play as “Lime Requirement Calculator”. For some of the area measurements, local units were added. The language can be chosen between English, Khmer and Lao.

It is potentially possible to expand the lime recommendation calculator to include fertiliser recommendations, although it would increase its complexity significantly. While the content of the lime rate calculator most likely won’t need any updates (unless there is a need to incorporate results from more scientific soil testing results), the fertiliser rate component would need to be maintained to include more up to date fertiliser recommendations for individual crops as they become available. Emerging new crops also need to be included as they become more popular.

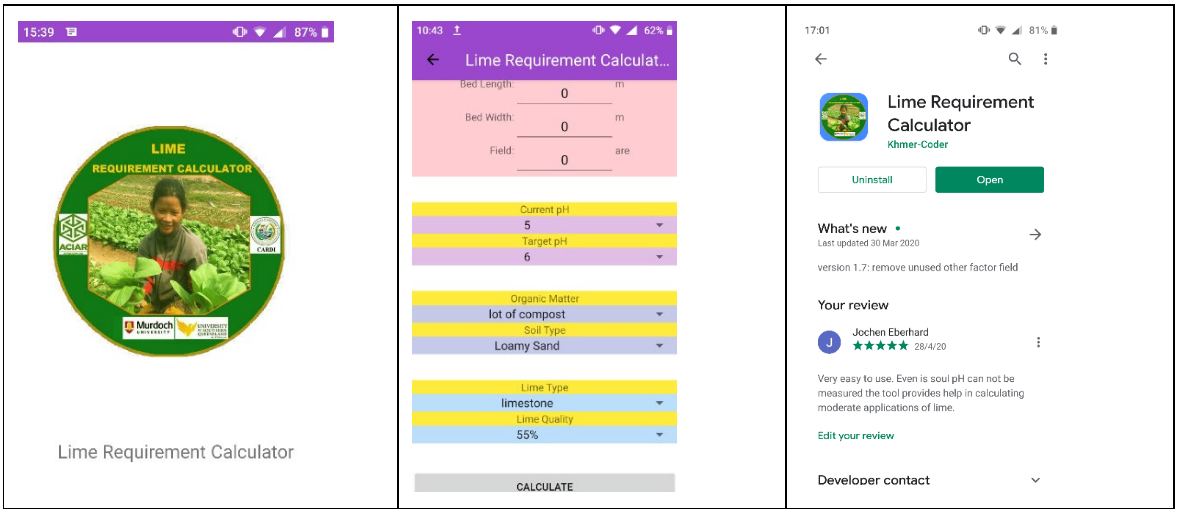


Figure 23. Screenshots of Lime Requirement Calculator

7.3.10 Discussion

7.3.10.1 The benefits of applying lime

Application of ag lime in both countries produced a significant positive effect on crop development and up to a 100% increase in yields. The effect was larger at most sites in Cambodia, while some sites in Lao PDR only had small responses. One reason for this difference is probably the difference in soil texture. Most soils in Cambodia used in this project had a very high fraction of sand (> 90%) which accelerates pH changes in response to lime application. Starting soil pH was on average below 5 which limits plant growth to a larger extent than the pH levels observed in Lao PDR of just above 5 or higher. The positive effect of a lime application on plant growth becomes more obvious the lower the initial soil pH. A third reason might have been the use of different formulations of ag lime material. In both countries, the lime materials were applied either at planting or within days before planting and incorporated mostly by hand. In Lao PDR ground limestone material was use, while the team in Cambodia had access to a formulation with burnt lime (40% CaO). Limestone is a slow reacting material which is very sensitive to the grade of milling and proportion of fine particles in the material. Normal management practice is to apply the limestone material at the end of the vegetable growing season (sometime in the rain season) to allow it to break down for a few months before the next crop gets planted. This practice was never tested, since it would have involved a complex administrative process even for trials at research facilities. The burnt lime product (40% CaO) used by the team in Cambodia is marketed as agricultural material and used almost exclusively in aquaculture to manage the quality of the water. CaO is a very fast reacting material that causes a sudden change in soil pH. This often leads to a spike in soil pH beyond the target range if larger quantities are applied. If the application happens close to transplanting, this spike in soil pH will have a negative impact on crop establishment. One irrigation trial on CARDI land failed probably for this reason. A blanket 2 t/ha (the maximum rate used in the project in Cambodia) was applied on soil with already high soil pH (above 6) just before planting. The quick release of the CaO product most likely raised the soil pH well above 8 at the time of planting, which caused a lot of transplants to fail to establish and the rest struggled to develop. Anecdotal evidence supporting this explanation is that plots receiving the highest rate of irrigation had slightly better plant populations, although these treatments had extended saturated soil conditions (no data collected as the trial was abandoned due to large fraction of missing plants in treatments and generally abnormal plant development).

In the last round of demonstrations in Cambodia with different rates of lime, some sites presented soil pH of around 7 or above with the highest lime application rate of 2 t/ha. Yield data suggests that some vegetables might reduce performance and yield when the soil pH is above 6.5. The observation that the relatively low application rate of 500 kg/ha of the product (40% CaO) in most demonstrations achieved the highest marginal increase in yield could be seen as supporting data, that lime materials based on Calcium Oxide need to be managed very carefully in order to avoid negative impacts on vegetable production. It also means that farmers only need to apply small quantities in order to get an immediate return. However, this effect only lasted one or two crops of short duration leafy vegetables. For a long-term strategy and for extension work, this relationship should be put into a concept where farmers would integrate applying lime into their routine fertiliser management. The same way they are used to applying urea and NPK to every crop they plant, they would do the same with the CaO product, i.e. apply small quantities for every crop. The knowledge of site-specific soil pH would not be necessary to calculate the right amount of CaO in order to avoid raising soil pH too much at least in the short to medium term. On the contrary, the advice for limestone material would need to be to apply the product well in advance, preferably at the end of the vegetable growing season, early in the rain season. Since limestone has a slower release characteristic, which also means a more prolonged change in soil pH, more focus is required on estimating the correct application rate. For this to be possible, testing soil pH is a key element.

Standard recommendations for liming should take the material type into account and suggest that only small amounts of lime be applied at each application, with a disclaimer that soil pH testing should be employed once a season or every second season to confirm soil pH isn’t raised above optimum levels. This approach, low application rates and frequent soil testing, is particularly important on soils with a high fraction of sand and a low buffer capacity and low organic matter content.

The lime requirement calculator app, developed in the X-project supports the move away from universal recommendations regarding lime application to more site specific soil pH management. Currently use of the app is limited to researchers as commercial soil pH testing is virtually unavailable in both Cambodia and Lao PDR. Without soil testing capacity farmers will struggle to improve the productivity of their acidic soils. The lime requirement calculator could be improved by adding recommended pH targets for specific crops. In this context, further research should be done into identifying optimum soil pH levels for typical vegetables grown in south-east Asia to provide proper and sound advice to farmers.

Particularly in Cambodia lime is promoted, primarily by word of mouth, often as some sort of fungicide. Susceptibility to crop disease is a side-effect of managing soil pH but leads to an ad hoc approach in the farming community, where lime is only used when crops show symptoms related to crop health. To address soil structural issues the use of gypsum should be investigated, although supply chain constraints at the beginning would be immense.

A component which wasn’t explicitly looked at in this project was the interaction of mineral fertiliser and soil pH and its implication for lime applications. Farmers use urea as the main form of nitrogen fertiliser due to its lower cost compared to NPK fertilisers. Application of urea on soil with limited ion buffer capacity (most tropical soils) causes an increase in acidity. These types of soils should be carefully managed by either avoiding mineral fertiliser with an acidic reaction or introducing a management plan to balance ag lime application with the type and amount of acidic fertilisers being used. This could be the unconscious motivation for most farmers to use lots of organic materials and a positive side effect of burning rice husks for charcoal. Anecdotal references have it that farmers often observe “fertiliser burn” when applying new types of fertilisers. Application rates in trials and demonstrations in the project on occasion were blamed for crop damage.

This relationship between acidic fertilisers and soil pH could explain to a degree why farmer practice in some of the trials and demonstrations performed well compared to the new treatments introduced (they used less urea) and others where new treatments introduced easily doubled the yield (high rates of urea as farmer practice).

7.3.10.2 The benefits of balanced NPK application rates and its interdependence with soil pH management

Field trials revealed that yields of leafy vegetables can be increased by up to 50% by applying standard NPK recommendations while reducing fertiliser input in most cases. Most trials and demonstrations showed that optimising NPK rates in combination with adjusting soil pH achieved the best results while each component by itself improves soil fertility. However, the different trends in fertiliser strategies in Lao PDR and Cambodia by smallholder farmers did have an impact on the results from the trials and demonstrations. In Lao PDR, the sparse usage of P and K with often reduced input of nitrogen compared to crop demand enabled the project to demonstrate that a more balanced NPK supply at rates more suitable to meet crop demand can increase yields quite dramatically. Even at relatively marginal improvements in yield, the economics proved to be positive.

In Cambodia, the project found that a more balanced and lower NPK supply to crops is possible without yield penalty, but reduces production costs for the farmer. The main driver for improved yields seems to be the management of the soil pH (acidity). Since the sites in Cambodia almost exclusively had non-replicated demonstrations, this assessment cannot be supported by statistical significance. However, there was a clear trend at all sites, which encouraged the project partners in Cambodia to recruit as many farmers as they could to demonstrate the approach of using lime to manage soil pH and standard NPK recommendations that are aligned more closely with anticipated crop demand.

While using standard nutrient requirements data to calculate optimised NPK recipes achieved yield improvements or significant reduction in fertiliser use, they were a one size fits all approach. Further optimisation could be achieved, if site-specific nutrient requirements could be calculated based on soil testing for N, P and K. While P and K are usually retained in the soil reasonably well, infrequent adjustments based on soil testing would be required to maintain optimum availability of these minerals in the soil. For nitrogen, the soil should be assessed before each planting so residual availability of nitrate can be taken into account. Since the size of vegetable crops in Lao PDR and Cambodia are frequently as small as 100 m^2, soil testing needs to be easy, locally available and cheap, without the need for high scientific accuracy. Further improvements could be made by developing scientifically sound recommendations for each province and region. However, this would take many years of trials of fertiliser rates for a large variety of crops.

Because of the close relationship between fertilisers and soil pH management where improvements in one or both will always lead to improved soil fertility and productivity, farm extension work can approach both subjects separately, and move the focus depending on the problem which seems more urgent, in order not to overload farmers with too many “demands” at once. For example, in Lao PDR, it seems that farmers often use insufficient amounts of mineral fertiliser as they are afraid of committing funds to crops with uncertain revenue. Recommending small increases in fertiliser application and/or applying low rates of ag lime will encourage more farmers to try and, according to all trials and demonstrations in this project, the move will improve yields and revenue.

7.3.10.3 The role of soil organic matter

Tropical soils are commonly low in organic matter. FAO reports levels of 0.1 – 1%. Naturally, soils with such low levels of organic matter are structurally fragile. Intensive farming with multiple crops per season and frequent soil cultivation quickly leads to soil structural instability. The observed levels of organic matter in the soils used for the replicated trials and demonstrations in this project frequently had high, and in some cases very high, levels of organic matter in the top 30 cm. Farmers seemed to be well aware that adding organic material to their intensively cropped soils is beneficial, and they appeared to do whatever they could afford to increase or at least maintain soil organic matter content. This statement is only valid for the land that is used for vegetable production, which is often clearly separated from the land used for rice production. Farmers therefore generally don’t need encouragement to improve and manage soil organic matter content of their soils. Poor soil fertility, particularly on the Cambodian lowland floodplains is more associated with soil texture (extreme sand fraction), and the associated low nutrient retention capacity. While the project attempted to address this problem by introducing more balanced, crop-specific fertiliser management to avoid fertiliser losses, the timing of fertiliser application should be included in future work, to improve productivity and fertiliser use efficiency further.

The replicated trials with organic fertilisers at the Horticultural Research Centre (HRC) and on some farms nearby in Lao PDR generally yielded at the lower end of what yields were achieved on commercial farms using mineral fertiliser. However, given the high variability of yields observed during the project across all activities, these results are within expectations. One of the reasons for lower yields could have been the lower plant density used at the HRC research station. Another aspect is that the rate of mineralisation and nutrient release from organic materials even under tropical conditions with high soil temperature and moist soil conditions is challenging to manage. While it can be assumed, that mineralisation is faster than in more temperate climates, the same strategies should be implemented in that multiple crops per dry season should be grown and the first crop being front-loaded with a surplus of compost to allow for the slower release. Also, a crop with a longer cropping period should be planted first. In contrast, shorter crops should follow later, to benefit from residual nutrients.

Strategies to manage application rates of organic fertilisers to match the nutrient release to the demand of the crops over an entire season are required to optimise organic crop production. This concept, while drafted for the last cropping season for the project (2018/19) couldn't be implemented since administrative processes require a much longer lead time than was available. Since this concept is similar to the plant nutrient budgeting for mineral fertilisers, it is unknown to farmers, and extension staff have no experience with it. It would require a lot more support over a longer time to move farm practices into this direction.

While there was a trend in the data that organic materials that were processed more intensively and aged longer, hence probably plant nutrients were more readily available, produced higher yields, more work should be done around methods of composting of organic materials to obtain a fertiliser that mimics mineral fertilisers better regarding the nutrient release and availability to allow farmers to easily use them as a substitute to mineral fertilisers. This approach would enable using universal fertiliser recommendations and would help to limit the overapplication of organic fertilisers, and so would also, at least partially, address the issue of potential supply limitation of organic fertilisers. The government should introduce guidelines and standards to support this development.

The use of rice husk as organic fertiliser should be evaluated further, particularly in the context of the common practice of partially burning the material. This practice has some positive side effects like reduction of weeds seed contamination, the minor alkaline effect of the ashes on soil pH; the charcoal fraction is inert, doesn't carry plant pathogens, and won't lock up nitrogen to break down (C:N ratio), but a lot of valuable carbon gets lost in the process, and only a small portion of the rice husks can be converted into soil organic matter. Burning rice husks should be investigated in more detail, and the benefits of not burning the material should be highlighted by investigating other treatment methods to achieve some of the positive side effects like disinfections.

7.3.10.4 Outcomes, impacts, constraints and future work in soil management

- **Scientific outcomes** Field trials revealed that yields of leafy vegetables can be increased by up to 50% by applying standard NPK recommendations while reducing fertiliser input in most cases. They also showed that even small applications of lime raise leafy vegetable yields by up to 100% within a crop cycle, particularly on sandy lowland soils in Cambodia. Liming has a bigger/faster effect on yield in sandy soils than in loamy soils. Standard fertiliser recommendations from other regions around the world are a suitable starting point to improve current farmer practices to manage soil fertility.
- **Capacity impacts:** All project participants learned a lot, knowledge gaps were identified and were addressed successfully. Development of the lime rate calculator is an important stepping stone to enable extension personnel to advise farmers on the correct use of ag lime to manage the acidity of their soils. All project participants are now better equipped to do similar work in the future, to better identify issues related to soil fertility and to take risks in pursuit of suitable answers.
- **Stakeholder engagement and community impacts:** Demonstration sites are cheap and very effective in getting farmers involved. A continuous and strong extension support with regular demonstrations at demonstration sites is required to encourage widespread uptake of fertiliser recommendations. In almost all demonstration and replicated trials, increased yields due to lime application and/or improved fertiliser management resulted in increased profits to the farmer. Improved fertiliser management could result in less N and P and more K being applied to vegetable crops, with overall savings on fertiliser costs to vegetable growers and benefits to the environment including a reduced nutrient leaching, nutrient runoff and reduced greenhouse gas emission.

- **Supply chain constraints**: There is limited availability of NPK fertilisers suitable for vegetable production, single nutrient fertilisers and lime at commune and village level. This limitation will hamper uptake of the project findings in rural farming communities.
- **Research operational constraints:** Some of the detail of experimental protocols got lost on its way between the Australian side and the implementing field officers. Projects should budget for translation services to eliminate this issue. Unseasonal rain in Champasak Province, Lao PDR, and Kampot, Cambodia, caused some replicated trials and demonstrations to fail.

Future work on soil fertility needs to include approaches to make soil analysis for plant nutrient availability easily accessible and affordable for smallholder farmers. A comprehensive list of local vegetables needs to be produced with estimated plant nutrient requirements and a trial program needs to be established to confirm and modify nutrient requirements.

Cooperation across the supply chain is needed to make suitable NPK fertilisers and ag lime available for vegetable growers. This needs to be in conjunction with extension support for farmers so they see the need to purchase these fertilisers.

7.4 Irrigation Scheduling (Objective 4)

The irrigation practices of smallholder farmers in Lao PDR and Cambodia are largely based on the custom of applying water twice a day, in the morning and evening. Very little attention has been given to understanding soil water holding capacity, the movement of water in the root zone, or the varying needs of the plant as influenced by crop type, developmental stage or time in the season. Some farmers alter their watering practice from twice a day to once a day later in the growing period, but such changes appear to be uncommon. As most watering is done by hand (either watering can or hand held hose supplied by a pump), watering in excess of crop demand has impacts on labour and pumping costs, as well as longevity of water supply in the dry season, and the potential to influence crop quality through waterlogging or increased disease incidence.

The program of work to develop appropriate irrigation scheduling methods for smallholder vegetable producers involved conducting baseline measurements in the field, comparative testing of alternative methods of scheduling, development of guidelines to assist irrigation scheduling, replicated experiments and farmer demonstrations to inform and validate the effectiveness of their use and preparation of some simple decision support tools to assist advisors and growers.

7.4.1 Baseline irrigation and soil water measurement

Baseline measurements of irrigation infiltration rate, distribution uniformity, application rate, daily application amount and soil water tension were recorded at three sites in Lao PDR and two sites in Cambodia, across a range of crops (lettuce, cilantro, cucumber, chilli) to identify and assess commonly used irrigation methods and practices. About 50% of the baseline data recorded was of satisfactory quality for reporting and the remainder were considered practice data as part of the capacity building activities. The examples reported here were considered indicative of the situation in the villages participating in this study.

7.4.1.1 Soil moisture tension

Tensiometric soil moisture sensors are relatively common in Western vegetable production systems due to their comparatively low cost, real time data logging, capacity to retrieve and store data, low maintenance, and simple installation. In this study, they were used primarily to establish baseline data on soil water content conditions and for subsequent research and demonstration farm sites.

Tensiometric granular matrix sensors (Watermark soil moisture sensor, Irrometer Co., Riverside, California) were installed in cilantro and lettuce crops on two smallholder farms in Lao PDR and cucumber and chilli crops in Cambodia in 2017 to measure soil moisture tension responses to irrigation and rainfall. The cilantro crop was in Vientiane Capital Province (Pakxapkao village, Xaithany district (18.1397°N, 102.7753°E) and the lettuce crop was in Huaha village, Hadxaifong district (17.8504°N, 102.6108°E)). The cucumber crop was in Koun Sat village, Tuek Chhou district, Kampot Province (10.5965°N, 104.2785°E) while the chilli crop was in Popis village, Siem Reap (13.36617°N, 103.764°E) (Uddin and McPhee, 2018). Each set of equipment consisted of six soil moisture and two temperature sensors connected to a data logger (Figure 24). The sensors were installed in accordance with the manufacturer's instructions at 15, 30 and 45 cm depth for the lettuce crop, and 10, 20 and 30 cm for the cilantro and cucumber crops. Data were recorded at two hourly intervals during November-December 2016 for the cilantro crop, and May-June 2017 for the lettuce crop, in Lao PDR, and March-June 2017 for the cucumber crop, and May-June 2017 for the chilli crop, in Cambodia. The baseline data recorded in 2017 was used to assess the effects of current farmer irrigation practices. The sensors were also used to collect data during subsequent research trials in Lao PDR in 2018.

Figure 24. Watermark data logger installed in cucumber field, Kampot, Cambodia.

Soil moisture tension data from a lettuce crop in Huaha village, Lao PDR, showed that the crop sometimes experienced water stress due to insufficient irrigation (Figure 25), as evidenced by a significant soil moisture tension peak of almost 250 kPa on 20 May 2017. Less severe water stress also occurred on 7 June 2017, and again just prior to harvest on 11-12 June 2017. Conversely, soil moisture data showed that the cilantro crop experienced no water stress and was likely over-irrigated (Figure 26). Data from the cucumber crop at Koun Sat village, Kampot Province, Cambodia (Figure 27) showed evidence of both over- and under-watering over the period 24 March - 12 May 2017. At early stages of crop growth, the combination of irrigation and rainfall on the same day exceeded crop demand, resulting in a soil moisture tension of zero for a short period. Similar situations occurred later in the crop with intermittent periods of slight water stress. The soil moisture data show that soil water content was often quite variable and at times indicated either potential water stress due to low soil water content, or possible waterlogged conditions due to an excess of water. The first season of field experience during this study indicated that this type of sensor was appropriate for research and baseline data gathering purposes, but not for farmers, as the equipment is expensive and requires training and skill for use in the field, particularly to ensure correct installation of the sensors.

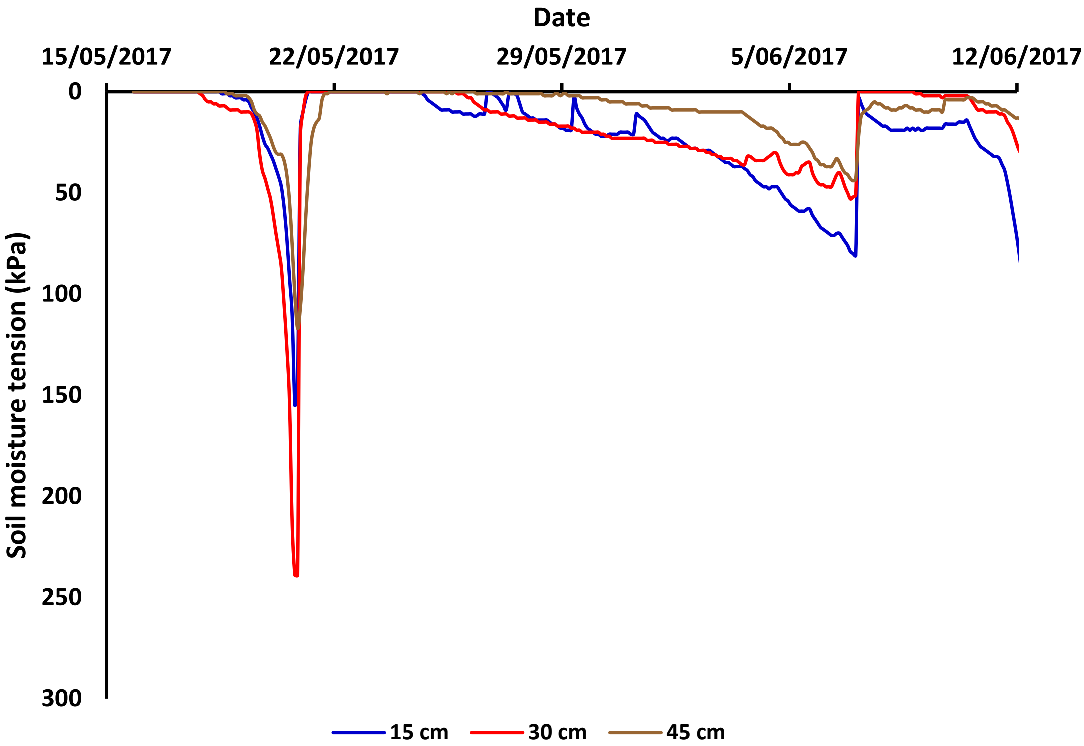


Figure 25. Soil moisture tension (kPa) measured in a lettuce crop at Huaha village, Vientiane, Lao PDR.

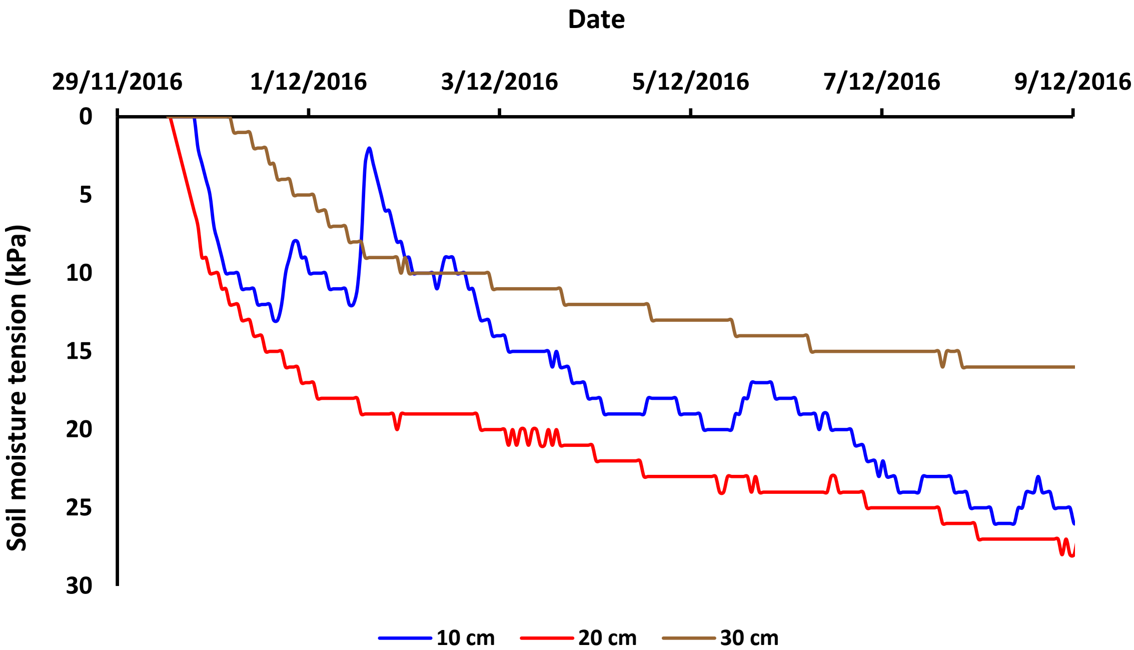


Figure 26. Soil moisture tension (kPa) measured in a cilantro crop at Pakxapkao village, Vientiane, Lao PDR.

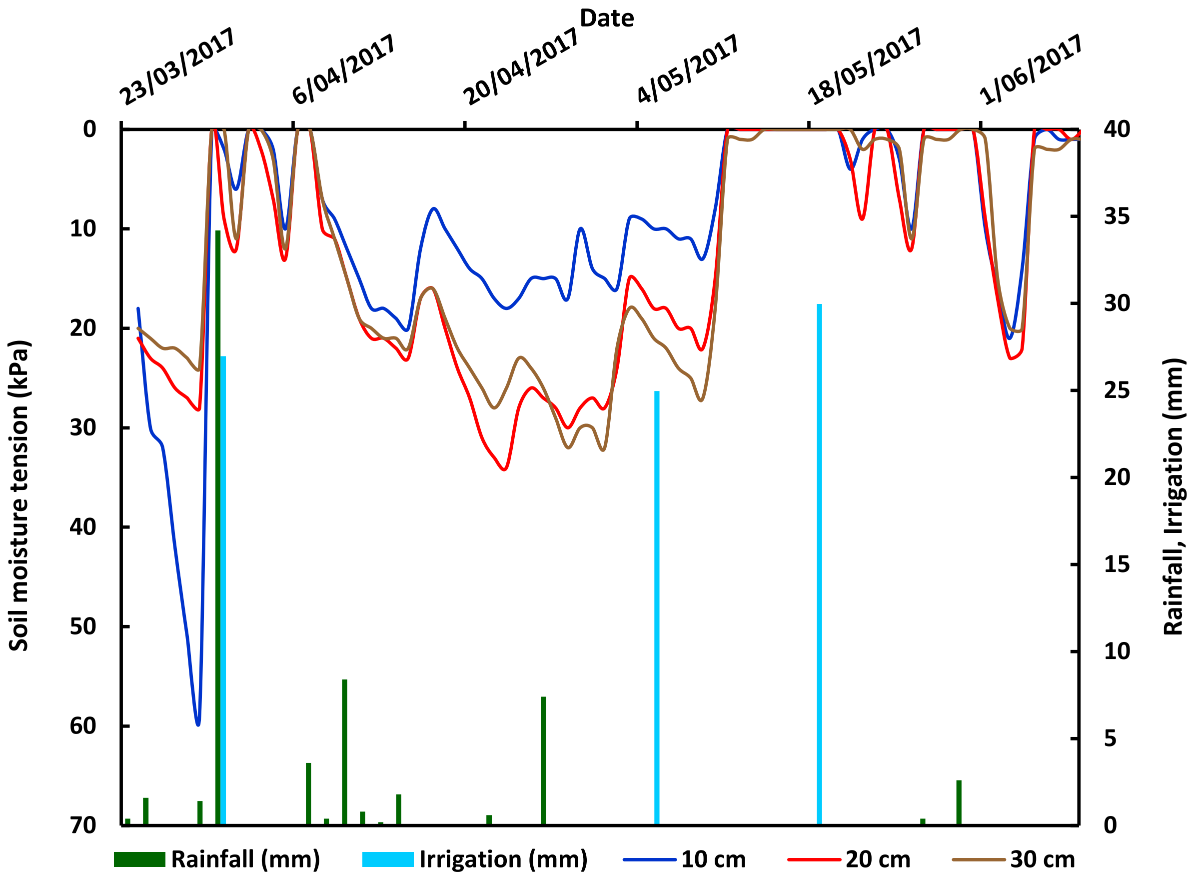


Figure 27. Soil moisture tension in kPa measured in a cucumber crop at Koun Sat village, Kampot, Cambodia.

7.4.1.2 On-farm recording of irrigation practices, Cambodia

Leafy vegetable crop irrigation was monitored by means of irrigation diaries on four farms in Choukk district (approx. 10.841ºN, 104.461ºE) Kampot, Cambodia, during March–April 2018 (Hin et al., 2018). The most common method of irrigation for smallholder producers is with the use of watering cans that are usually either 12 or 15 l capacity. Irrigation usually occurs twice a day (early morning and evening). The irrigation diaries and watering can volume enabled calculation of applied amounts to be compared to predicted demand.

Table 16 shows the total number of 15 l watering cans, and the total amount of water applied to each of the crops monitored in Kampot province in 2018. As the crops were all leafy vegetables with similar growth habits and growing periods (ranging from 21-24 days), their water demand would have been similar. However, Table 16 shows an almost 2-fold difference in the range of application amount for the crops.

Table 16. Total amount of water applied to similar crops in the same growing season on four farms in Kampot Province, Cambodia.

Farm no.	Total number of watering cans	Total amount (l/m^2)
1	67	83.8
2	86	107.5
3	46	57.5
4	48	60.0

Figure 28 shows the daily application at each farm compared to a simplified daily ET_c calculated using the Penman-Monteith method (Allen et al., 1998). The crops at farms 1 and 2 were over-watered for the whole growth cycle, by almost double the amount for varying periods. For most of the crop cycle, these two crops could have managed with just one watering in the morning. The crops at farms 3 and 4 were slightly overwatered in the first few days, and slightly underwatered for most of the growing period.

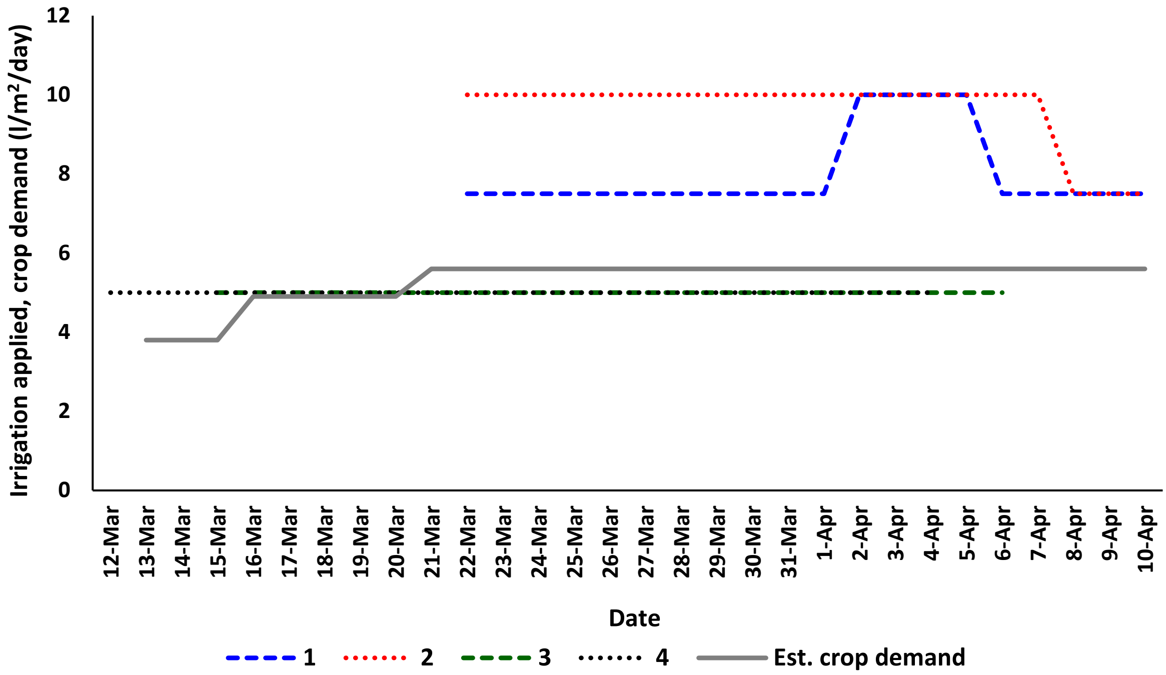


Figure 28. Daily application measured on four farms in Kampot Province, Cambodia, in 2018 showing differences in the amount of water applied to similar crops in similar growing conditions compared to simplified estimated demand based on ET_c.

7.4.2 Evaluation of scheduling methods

A range of soil, plant and weather-based methods can be used to support irrigation scheduling decisions (Appendix in Section 11.3). Two different methods of monitoring and estimating crop water use were evaluated as part of this study:

1) Mini-evaporation pans - measurement of water level differences in Class A evaporation pans combines the effects of wind speed, temperature and solar radiation on evaporation, thereby providing a realistic insight into how much water has evaporated from the area. This can then be used to schedule irrigation frequency and application. Standard Class A pans are costly for smallholder farmers. As low-cost evaporation pans made from 200 L drums have been successfully used in Australia to assist pasture and sugarcane irrigation scheduling, it was proposed that simple, locally available buckets may be suitable for scheduling vegetable crop irrigation in developing countries.

2) Penman-Monteith method of estimating crop evapotranspiration (Allen, 1998) - estimating ETo from weather data can be an effective way of predicting irrigation requirements. However, local weather data is limited in developing countries, making it necessary to rely on online open source weather data (e.g. NASA POWER - https://power.larc.nasa.gov/data-access-viewer/). The NASA POWER data base contains all the data required (i.e. solar radiation, maximum, minimum and dew-point temperature, wind speed and relative humidity) for the Penman-Monteith FAO 56 method of estimating crop water demand.

7.4.2.1 Mini-evaporation pans

A mini-evaporation pan field trial was undertaken at the University of Southern Queensland, Toowoomba (-27.6094ºN, 151.9296ºE) from May-August 2017 to compare evaporation rates from different sized pans against weather station data. Different water level measuring methods were compared, as well as the influence of temperature, wind speed, solar radiation and varying water levels in the mini-pans. Four different mini-evaporation pans were used: part (~ ⅓ depth) of a 200 l drum, and three plastic buckets with volumes of 20, 11.1 and 5 l (Table 17 and Figure 29).

Table 17. Mini-evaporation pan dimensions and starting water level heights (mm).

Description	Height (mm)	Diameter (mm)	Starting water level (mm)
Part drum	30.0	553.7	205
20 l bucket	41.0	284.0	260
11.1 l bucket	19.4	209.0	130
5 l bucket	22.5	282.7	180

Each container had a clear plastic ruler glued to its inside wall to measure the water level (Figure 29) and was filled with water to its respective starting level at the beginning of the trial. The water level of each pan was measured at 9 a.m, mostly every second day, with some measuring periods extending to three or five days. The difference in successive readings was recorded and the containers were then refilled to their original starting water level. The volume of water used to refill was used to calculate the evaporation. Rainfall was accounted for in the estimation of the water evaporated. Evaporation (calculated as FAO24 Reference Crop Evapotranspiration) and other weather data were obtained from a weather station (WeatherMaster 2000, Environdata, Warwick, Australia) located 20 m from the test pans. Evaporation data from the four mini-evaporation pans and the weather station were compared using a linear regression analysis. Significant relationships, which varied according to bucket size and shape, were determined between the weather station and the mini-evaporation pan data (Figure 30). The data show that evaporation from the largest mini-evaporation pan, the part drum, had the closest relationship to evaporation measured by the weather station, with R2 = 0.89 (Figure 30, Table 18). This was followed by the 20 l bucket with R2 = 0.81.

Figure 29. Different containers used as evaporation pans showing various sized plastic buckets (left) and a part 200 l drum (right).

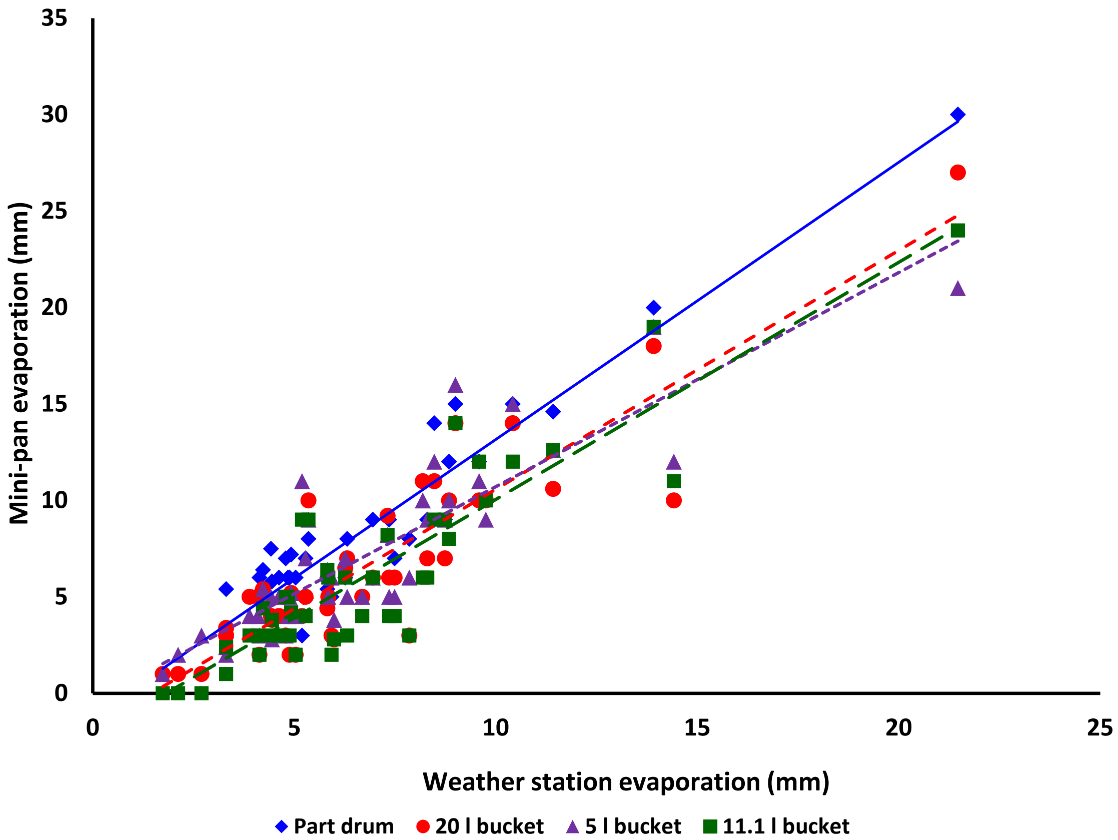


Figure 30. Linear relationships between four different styles of mini-evaporation pan and weather station evaporation data from an experiment conducted at University of Southern Queensland, Australia.

Table 18. Linear regression and measures of statistical fit from an analysis comparing evaporation rates of each pan to weather station evaporation data.

Mini-evaporation pan	Regression equation	R^2	RMSE	MAE	s.e.
Part 200 l drum	Y = 1.44x – 1.21	0.89	1.69	1.31	0.85
20 l bucket	Y = 1.24x – 1.80	0.81	2.15	1.64	0.73
11.1 l bucket	Y = 1.23x – 2.24	0.80	2.12	1.53	0.67
5 l bucket	Y = 1.11x – 0.39	0.77	2.15	1.60	0.73

Y = pan evaporation (mm), x = weather station measured evaporation (mm), RMSE = Root Mean Square Error, MAE – Mean Absolute Error, s.e. – standard error

The regression equations (Table 18) relate the evaporation data from the mini-evaporation pans to that obtained from the weather station. The relationships were considered sufficiently robust so the procedure used could be followed for other mini-evaporation pans in other environments and climates to obtain appropriate regression equations. A mini-evaporation pan was installed as part of field experiments in Koun Sat village, Kampot, Cambodia in 2017, but the field site and the method were subsequently abandoned due to excessive rainfall and a succession of flooding and waterlogging events at the site.

7.4.2.2 NASA POWER weather data and ETo-based method

NASA POWER weather data (https://power.larc.nasa.gov/data-access-viewer/) were compared with weather station data recorded at the Cambodian Agricultural Research and Development Institute (CARDI), Phnom Penh, Cambodia (11.4766°N, 104.8079°E) during the period 22 March 2014 to 12 July 2017. Daily weather data recorded at CARDI included incoming solar radiation, mean temperature, relative humidity, wind speed and atmospheric pressure. Due to equipment malfunction at various times, the data were not continuous over the 1209 day period, covering a total of 834 days in three time blocks that ranged from three to 19 months duration. NASA POWER weather data for matching periods were downloaded from the NASA POWER database. Individual day data were averaged to provide day of year (DOY) data. The daily reference evapotranspiration (ETo) was estimated using the procedures given by Allen et al. (1998). Pair-wise comparisons of each weather parameter were made using linear regression. Root mean squared error (RMSE), mean absolute error (MAE), percentage error of estimate (% Err of Est.) and standard error (s.e.) were used to evaluate the accuracy of NASA POWER weather data compared to the weather station recorded data.

Comparisons between weather data measured at the CARDI weather station and data retrieved from NASA POWER are shown in Table 19 and statistical performance evaluations in Table 20. The difference between ET_o estimated from the weather data and from NASAPOWER data is about 13%, with RMSE = 0.81 mm day^{-1} and R^2 = 0.74 (Table 20, Figure 31). The statistical evaluation between CARDI weather station data and that obtained from the NASA POWER database was sufficiently robust to give confidence that NASA POWER data could be used for locations which did not have locally recorded data.

Table 19. Comparison of weather data downloaded from the NASAPOWER database and weather data measured at CARDI, Phnom Penh, Cambodia, including the ETo calculated from each data source.

		CARDI			NASA POWER		
Parameter	Units	Max	Min	Avg	Max	Min	Avg
Pressure	hPa	101.4	100.4	100.8	100.9	100.0	100.4
Relative humidity	%	88.4	51.4	70.0	92.5	39.5	71.2
Solar radiation	MJ m^{-2} day^{-1}	22.8	1.6	17.0	24.7	4.9	18.6
Temperature	°C	30.8	24.2	28.0	33.3	24.9	28.4
Wind speed	m s^{-1}	3.4	0.7	1.7	3.5	0.6	2.0
ET_o	mm day^{-1}	5.5	-0.4	3.7	7.0	0.4	4.2

Table 20. Statistical evaluation of the relationships between weather data downloaded from the NASAPOWER database and weather data measured at CARDI, Phnom Penh, Cambodia, including the use of those data to calculate ETo.

Parameter	Units	RMSE	MAE	% Err of est.	Mean ratio	s.e.	Slope	R^2
Pressure	hPa	0.41	0.41	0.41	1.00	0.00	0.87	0.98
Relative humidity	%	8.08	7.09	1.61	0.98	0.42	1.65	0.75
Solar radiation	MJ m^{-2} day^{-1}	2.40	2.09	9.78	0.91	0.09	0.99	0.73
Temperature	°C	1.28	1.01	1.48	0.99	0.06	1.13	0.57
Wind speed	m s^{-1}	0.54	0.44	21.6	0.82	0.02	0.70	0.37

Parameter	Units	RMSE	MAE	% Err of est.	Mean ratio	s.e.	Slope	R^2
ET_o	mm day^{-1}	0.81	0.67	13.4	0.88	0.03	1.19	0.74

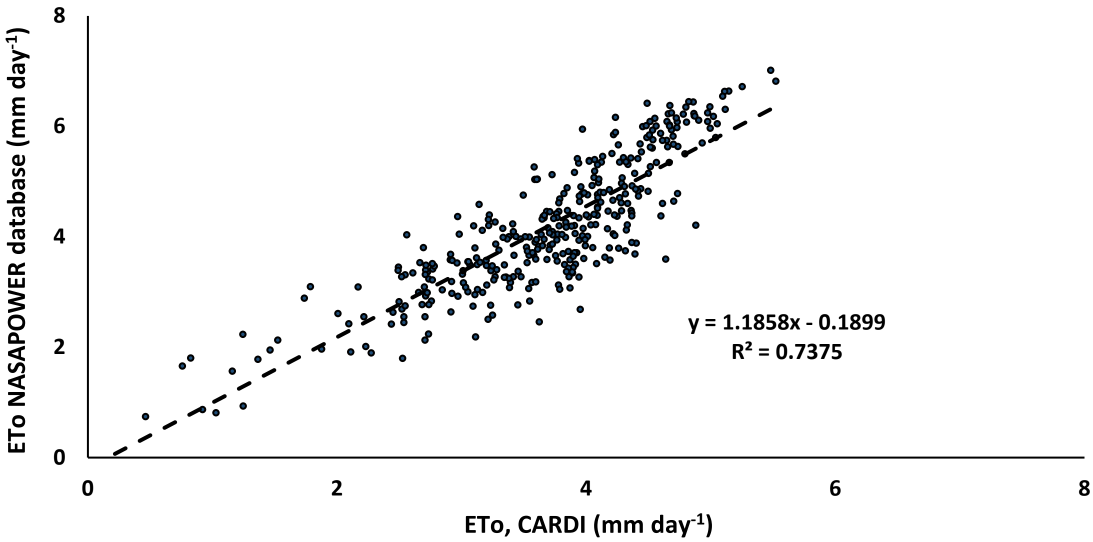


Figure 31. ET_o calculated from weather data measured at CARDI and estimated from corresponding NASAPOWER weather data.

7.4.3 Field experimentation and demonstrations

7.4.3.1 Lao PDR

Irrigation field trials were conducted over two seasons (2018, 2019) at the National University of Laos (NUoL, 18.124334ºN, 102.791842ºE) (Somphou et al., 2018, 2019). The objective of the trials was to assess the effectiveness of using predicted ET_c as a means of scheduling daily irrigation applications for lettuce (*Lactuca sativa)*. In the 2018 experiment, three irrigation treatments were assessed in conjunction with three lime rates in a split-plot, four replicate design. In 2019, three irrigation treatments were assessed alone. In both seasons, the irrigation treatments were farmer practice (I1), and irrigation based on predicted ET_c, once per day (I2) and every second day (I3). Table 21 shows the amount of water applied in the different irrigation treatments for the two seasons of field experimentation. The amounts applied each year differed slightly based on refinement of the method and differences in transplanting dates and hence predicted ET_c. All treatments were irrigated twice per day for the first 5-6 days after transplanting to ensure the bare-rooted transplants were kept adequately moist to overcome transplant shock.

Table 21. Irrigation treatments applied to lettuce crops grown over two seasons at National University of Laos, Vientiane Capital Province, Lao PDR.

	Irrigation treatments (2018)		
DAT (dates)	I1	I2	I3
DAT 1-6 (31/3-6/4/18)	9 l/m^2/day (4.5 l/m^2 morning and evening)	6 l/m^2/day (3 l/m^2 morning and evening)	6 l/m^2/day (3 l/m^2 morning and evening)
DAT 7-14 (7-13/4/18)	9 l/m^2/day (4.5 l/m^2 morning and evening)	4 l/m^2/day applied each morning	8 l/m^2 applied every second morning

DAT 15-28 (14-27/4/18)	9 l/m²/day (4.5 l/m² morning and evening)	4.5 l/m²/day applied each morning	9 l/m² applied every second morning
	Irrigation treatments (2019)		
DAT (dates)	**I1**	**I2**	**I3**
DAT 1-5 (16-20/2/19)	9 l/m²/day (4.5 l/m² morning and evening)	3.7 l/m²/day (1.85 l/m² morning and evening)	3.7 l/m²/day (1.85 l/m² morning and evening)
DAT 6-12 (21-27/2/19)	9 l/m²/day (4.5 l/m² morning and evening)	2.6 l/m²/day applied each morning	5.2 l/m² applied every second morning
DAT 13-22 (28/2-6/3/19)	9 l/m²/day (4.5 l/m² morning and evening)	3.4 l/m²/day applied each morning	6.8 l/m² applied every second morning
DAT 23-29 7-16/3/19)	9 l/m²/day (4.5 l/m² morning and evening)	4.3 l/m²/day applied each morning	8.6 l/m² applied every second morning

Notes: DAT – days after transplanting

There were no statistically significant differences in yield between the irrigation treatments in either year of field experiments. However, there were large differences in the amount of water applied, resulting in significant differences in irrigation water use efficiency (IWUE) (Table 22).

Table 22. Yield, water applied and irrigation water use efficiency (IWUE) measured in two experiments at National University of Laos, Lao PDR.

		Yield (kg/m²)		Water applied (l/m²)	IWUE (g/l)	
Year	**Treatment**	**mean**	**s.e.**		**mean**	**s.e.**
	I1	1.55[a]	0.14	252	6.2[a]	0.96
2018	**I2**	1.66[a]	0.14	133	12.5[b]	0.96
	I3	1.81[a]	0.14	137	13.2[b]	0.96
	I1	1.84[a]	0.38	261	7.1[a]	3.56
2019	**I2**	2.28[a]	0.38	104	22.0[b]	3.56
	I3	2.65[a]	0.38	103	25.7[b]	3.56

Irrigation treatments: I1 – farmer practice (water twice per day); I2 – water once per day to predicted ET_c; I3 – water once every second day to predicted ET_c. Different letters in the same column for each year signify statistically significant differences $p<0.05$.

7.4.3.2 Cambodia

During the 2019 growing season, two irrigation methods were demonstrated on farms in Kampot Province growing mustard greens (*Brassica integrifolia),* and Siem Reap Province growing bok choy (*Brassica rapa* subsp. *Chinensis)* (Hin et al., 2019). The two methods were famer irrigation practice (twice a day, early morning and evening) and irrigation based on predicted crop water demand (Allen et al., 1998). Details of the irrigation treatments are given in Table 23.

Table 23. Irrigation scheduling methods used on farm demonstration sites in Kampot and Siem Reap Provinces, Cambodia, in the 2019 growing season.

Irrigation treatment	Details
Farmer Practice	Kampot: 2 times/day, 8-12 l/m^2 per day Siem Reap: 2 times/day, 10-14 l/m^2 per day
FAO ET_c guideline	1 time/day, 3-5 l/m^2 per day according to predicted demand based on crop type, crop growth stage and province

Applying irrigation according to predicted crop demand using FAO ET_c guidelines resulted in much lower water use than farmer practice without any noticeable change in crop yield (Table 24). The end result was a 2.6-fold improvement in irrigation WUE for both crops. The comparison between water applied using the FAO ET_c guidelines and that applied as farmer practice is shown in Figure 32.

Table 24. Water application, leaf yield and irrigation WUE data for leafy vegetable crops in Kampot and Siem Reap Provinces, 2019. Data are the mean of three sites in Kampot Province for mustard green, and two sites in Siem Reap Province for bok choy

	Mustard green			Bok choy		
Irrigation method	Water applied (l/m^2)	Leaf yield (kg/m^2)	IWUE (g/l/m^2)	Water applied (l/m^2)	Leaf yield (kg/m^2)	IWUE (g/l/m^2)
Farmer Practice	211	3.05	14.1	245	2.44	10.0
FAO ET_c guideline	81.1	3.02	37.2	95.6	2.46	25.7

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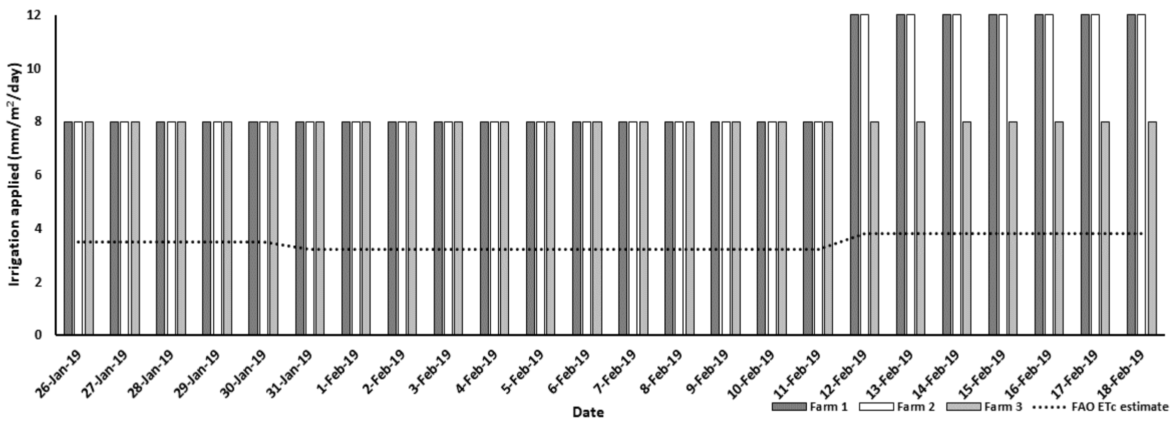

Figure 32. Farmer irrigation practice for mustard green in Kampot province in comparison to modelled crop water demand based on FAO ET_c

7.4.4 Development of decision support tools for irrigation scheduling

Baseline measurements of soil moisture and comparison of current irrigation practices against crop water demand as predicted by ET_c (Penman-Monteith method) (Allen et al., 1998) show that normal farmer irrigation practices were suboptimal for the production of irrigated leafy vegetables in Lao PDR and Cambodia (Uddin and McPhee, 2018). The results of replicated experiments in Lao PDR and farmer demonstration sites in Cambodia indicated that using predicted ET_c as the basis for managing irrigation applications was an appropriate approach, with 2-3-fold improvements in irrigation WUE compared to farmer practice (Somphou et al., 2018, 2019; Hin et al., 2018. 2019). The easiest change to make to current approaches was to reduce watering to once a day, since the most common evidence of suboptimal irrigation management was overwatering by a factor of approximately two. Given that the irrigation systems of interest in this study were mostly watering cans and hand-held hoses, a change to once a day watering, with total application being approximately 50% of that previously used, resulted in savings of water, pumping costs (where relevant) and labour.

However, while advice to water once a day is a very simple means to initiate change, such guidance ignores the nuances associated with differing water demand through the crop growth period and across the season, and for situations where current practice was not simply the application of double the amount of water required. Consequently, having proven that the ET_c approach led to major improvements in irrigation management, it was necessary to develop tools that allowed farmers to use this information without over-simplification (and potential adverse outcomes) or the complications of ET_c calculation.

7.4.4.1 Daily application tables

The first step in the development of tools for use by farmers and advisors was the creation of daily application tables. These were developed for the dry season production period for each district involved in the study (four in Lao PDR and three in Cambodia), and for leafy vegetable crops of different growing duration, namely short term (25-25 days from transplant to harvest), medium term (40-50 days) and long term (55-65 days). The districts were: Lao PDR – Hadxaifong and Xaithany (Vientiane Capital province) and Phunthong and Paksong (Champasak province); Cambodia – Kampot and Siem Reap provinces and

Phnom Penh. The tables are based on ETo calculations modelled on 33 years of NASA data for each of the districts involved. Crop demand (ET_c) was calculated from ET_o and the relevant crop factor (k_c). As part of the calculation process, crop growth stages from Allen et al. (1998) were adjusted in proportion to predicted crop duration. An example of the daily application tables for the district of Paksong, Lao PDR, is shown in Figure 33.

Paksong

Irrigation schedule for quick growing (25-35 days) dry season (1 Oct – 30 Apr) leafy vegetable crops – e.g. lettuce, mustard green, Chinese cabbage, Pak choy, Bok choy

	Days after Transplanting		
Paksong	1-7	8-17	Through to harvest
Transplanting Date	Daily Application (l/m²)		
Between 1-Oct and 28-Nov	3	3	3
Between 29-Nov and 21-Jan	4	3	4
Between 22-Jan and 13-Feb	4	4	5
Between 14-Feb and 30-Apr	4	4	4

Irrigation schedule for medium term (40-50 days) dry season (1 Oct – 30 Apr) leafy vegetable crops – e.g. Chinese kale

	Days after Transplanting			
Paksong	1-5	6-11	12-27	Through to harvest
Transplanting Date	Daily Application (l/m²)			
Between 1-Oct and 28-Nov	3	2	3	4
Between 29-Nov and 21-Jan	4	3	3	4
Between 22-Jan and 13-Feb	4	3	4	5
Between 14-Feb and 30-Apr	5	3	4	5

Irrigation schedule for longer (55-65 days) dry season (1 Oct – 30 Apr) leafy vegetable crops – e.g. broccoli, cauliflower

	Days after Transplanting			
Paksong	1-5	6-15	16-34	Through to harvest
Transplanting Date	Daily Application (l/m²)			
Between 1-Oct and 28-Nov	3	2	3	4
Between 29-Nov and 21-Jan	4	3	3	4
Between 22-Jan and 13-Feb	4	3	4	5
Between 14-Feb and 30-Apr	5	3	4	5

Figure 33. An example of daily application tables (for Paksong district, Lao PDR) showing recommended application rates for leafy vegetables of three different growth durations.

The recommended daily application rates are an approximation of what would be obtained if being guided strictly by the Penman-Monteith calculation process. Recommended rates in the schedule were based on blocks of time (Figure 34) as ET_c calculations done on a daily basis would be impractical for the purpose of guiding irrigation decisions by smallholder farmers using watering cans and hoses. ETo data were analysed to determine on which dates during the growing period the absolute cumulative daily change in ETo exceeded 10% of the ETo at the start of a given time block. These dates were used as change points for adoption of a new ETo. Therefore, the ETo used for any given block of time was determined by the ETo at the change date. An example of the difference between predicted ET_o (5-day moving average) and the ETo used to calculate ET_c for the Paksong daily application tables is shown in Figure 33.

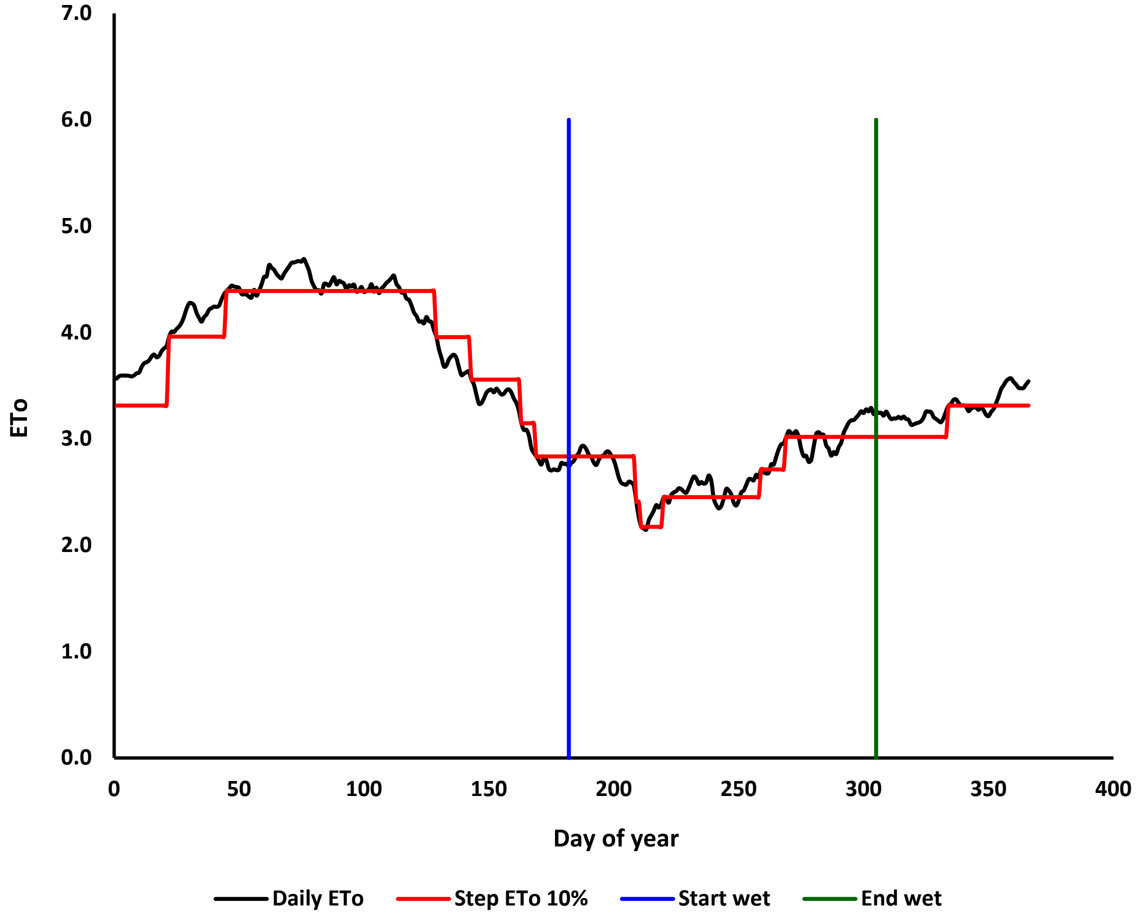

Figure 34. 5-day moving average ETo, and ETo approximated on absolute cumulative 10% change in ETo for Paksong district, Champasak province, Lao PDR.

Allowance was made to provide irrigation in excess of plant demand in the days immediately after transplanting. Given the climate and current transplanting techniques using bare rooted seedlings, there is significant transplant shock. It is common practice to water twice a day during this period, and application amounts were based on bare earth ETo for the period immediately after transplanting, after which the schedule followed the normal growth stage sequence outlined in Allen et al. (1998).

Mid-stage growth application rates were used up to harvest, as leafy vegetables are harvested fresh and consume water at peak rates right up to harvest. Calculations of ET_c were initially done to an accuracy of 0.1 mm (0.1 l/m^2), but such accuracy is unlikely to be obtained with the hand-held application technologies used by smallholder growers. In order to provide a margin of safety for the 10% ETo step analysis, application rates ending in 0.3 or greater were rounded up to the next whole l/m^2, while those 0.2 and below were rounded down. Hence, the application rates in the tables (Figure 33) were always given in whole numbers.

7.4.4.2 Development of nomograph

Provision of simplified daily application tables to guide growers in their irrigation management was the first step in improving irrigation management. However, few, if any, growers have the means to measure their application rate with any degree of accuracy or consistency. Therefore, it was concluded that application advice had to be given in a form that was more meaningful to end users, such as the number of watering cans per crop bed, or the time required to water a crop bed knowing the output of a hand-held hose system. All of these calculations are very simple to perform on a computer, calculator or smart phone app. However, smart phones are not widely used in some areas, so while an app is a likely future step, a low technology approach was taken in the first instance.

A nomograph was developed (pynomo.org) that allows advisors and farmers to calculate the number of watering cans or minutes of hose watering based on knowledge of bed size (length and width in m), daily application rate (obtained from the appropriate table) and system capacity, either watering can volume (l) or hose output (l/min). Figure 35 shows a worked example of the nomograph for the case of a crop bed 10 m long by 1.2 m wide, requiring a daily application of 6 l/m^2 using a watering can of 12 l capacity.

The tables, nomographs and training materials (printed and video) that were developed were produced in Laos and Khmer languages (see 10.2.4 for a full list of materials) to aid adoption of the techniques by local agricultural advisors and farmers.

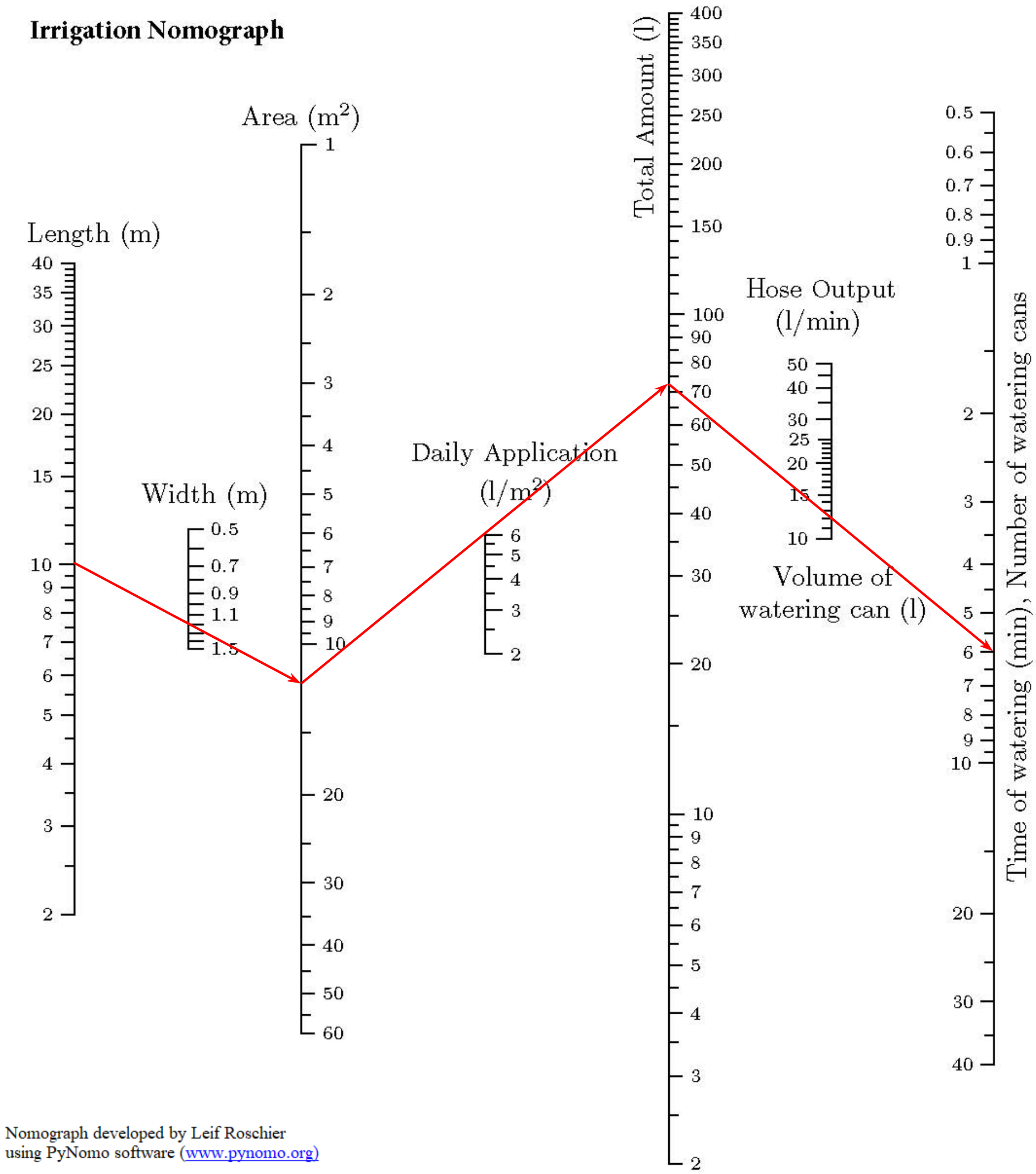

Figure 35. Nomograph developed for use by advisors and smallholder farmers to calculate the number of watering cans, or duration of hose watering, required to apply the recommended daily irrigation application to leafy vegetables in Lao PDR and Cambodia.

7.4.5 Discussion

This project focused on the issue of applying irrigation water in accordance with predicted crop demand. Introduction of new irrigation application technology has been a feature of other work in developing countries (Bhattarai et al., 2011; Palada et al., 2011). Badgery-Parker et al. (2020) found that a lot of farmers who have adopted new irrigation technology (such as drip irrigation) as a result of earlier development projects and activities are under-irrigating their crops by virtue of trying to irrigate too much area at the same time, and hence not achieving adequate DU or output due to limited pressure in the system. This underscores the point that scheduling, and understanding crop demand, is more important than the introduction of new technology. The approach of SMCN/2014/088 of focusing on getting the right amount of water applied has been very valuable. It is important to improve the understanding of farmers on the importance of applying water to meet (and not exceed) predicted crop demand, which can be done with training and management and for no extra capital cost. If farmers irrigate properly and reap the financial rewards of less labour and potentially better crops, they might then be in a position to afford an upgrade to drip or other systems that can be managed with a better understanding of crop demand.

A major challenge was to decide which method to use for irrigation scheduling. Early attempts to implement the use of mini-evaporation pans (i.e. evaporation pans made using locally available materials, rather than the standard, and expensive, Class A pan) in Cambodia were unsuccessful due to unseasonal weather conditions which resulted in the flooding, and subsequent loss, of trial sites. This is not to say the mini-evaporation pans might not have a place in smallholder irrigation scheduling (Vinh et al., 2015), it's just that attempts to validate their use, and then embark on appropriate training in their use, were thwarted by trial site failures and time limitations. Tensiometric soil sensors were used in both countries to establish baseline data on soil water content. The sensors were also deployed in field experiments that assessed the effectiveness of the ET_c approach to irrigation scheduling, but the technology is far too expensive and complicated for routine use by farmers. Cheaper technologies have become available more recently (e.g. Chameleon) but at the time this work was undertaken, those technologies were still relatively expensive and in a state of continuing development.

The use of predicted daily ET_c based on the Penman-Monteith model involves considerable mathematical processes to arrive at an estimate based on long-term modelled climate data (Allen et al., 1998). This is clearly beyond the capabilities of smallholder farmers. The approach used in the project distilled daily predicted ET_c into recommended application rates for key stages of crop growth based on a range of planting dates that were determined by significant changes in ET_c due to seasonal climate variation. These were presented in daily application tables, which showed the amount of water to be applied (mm or l/m^2) for various growth stages and times of the season. These tables provided the basis for field experiments and demonstrations to assess the value of the approach, but without an easy means to measure application rate, the information is of limited use to smallholder farmers.

A nomograph was subsequently produced that is used in conjunction with the daily application tables to arrive at guidance on how many watering cans to use, or how many minutes to water using a hose, in order to apply the correct amount of water. This process requires knowledge of a few key factors:

- Dimensions of the crop bed
- Volume of watering can or hose output/minute
- How to use the daily application tables

Training materials related to the process of determining effective irrigation scheduling were prepared and provided to project partners, and a limited number of training sessions (two in Cambodia, one in Lao PDR) were conducted prior to COVID-19 restrictions.

This project has focused on the big gains to be made in irrigation scheduling, demonstrating that the predicted ET_c approach can save in excess of 50% of the water (and labour) used in leafy vegetable irrigation in Lao PDR and Cambodia. The widespread uptake of this approach would have significant implications for on-farm labour and water storage and supply management in both countries. For example, having demonstrated irrigation WUE improvements of 200-300%, growers could potentially produce 2-3 times more leafy vegetables without needing access to any more land, water or labour. Widespread adoption of these findings at a national level would make a significant contribution to vegetable self-sufficiency in Cambodia and Lao PDR. Nevertheless, there are still barriers to uptake of the practice, requiring more training and extension. Refinement and greater uptake of the process could conceivably be facilitated by the development of a mobile phone app as an alternative to the nomograph and daily application tables.

7.4.6 Summary

- Mini-evaporation pans, soil moisture sensors and the Penman-Monteith model for predicting crop water demand (ET_c) based on long-term modelled climate data approaches were assessed for their suitability improving irrigation scheduling. Of these, the predicted ET_c method was chosen as the most appropriate approach for making rapid improvements in irrigation management by smallholder farmers.
- A replicated trial at Siem Reap in 2016-17 season showed that varying water application in line with calculated crop demand at different stages of crop development gave better crop growth and yield compared to the farmer's practice of applying the same amount of water daily throughout the cropping period.
- Farmer demonstration sites established for lime and NPK (Objective 3) in 2017-18 were used to gather information on irrigation application rates in Kampot province, Cambodia. This showed applications ranging from just below crop demand in early crop growth stages to 150-200% above crop demand for most of the growing season.
- The 2018-19 NUoL trial (3rd season) showed that irrigation treatments managed on predicted ET_c used less than half the water and labour of farmer practice, and gave yield increases of 26-72%, although high data variability meant there were no statistically significant differences. Irrigation WUE improved 2-3 fold. Similarly, farmer demonstration sites in Cambodia in 2018-2019 showed 2.5-fold improvements in irrigation WUE using watering cans (Kampot) and hand-held hoses (Siem Reap). In the case of Kampot province farmers, the reduction in water use (and hence also labour) was in the order of 60% compared with farmer practice.
- Daily application tables were produced for each province/district involved in the project, showing the amount of water that should be applied based on duration of crop (short, medium or long growing period), transplanting date and the number of days after transplanting.
- A nomograph was developed to use in conjunction with the daily application tables. This allows easy calculation of the amount of water to apply to a crop given changing water demand between crops, locations, times of the season and developmental stages of the crop.

- Training documents demonstrating the use of the daily application tables and the nomograph were produced for Cambodian and Laos project partners, and provided in English, Khmer and Laos.
- Instructional videos were produced to demonstrate the use of the daily application tables and nomograph, and provided to project partners in English, Khmer and Laos.
- Using the irrigation guidelines and decision support tools developed in this project, growers could potentially produce 2-3 times more leafy vegetables without needing access to any more land, water or labour.

7.5 Capacity building and technology adoption (Objective 2)

The Participatory Impact Pathways Analysis (PIPA) identified that, in both countries, limitations of vegetable production systems related to adoption of new practices were farmer confidence and knowledge, the availability of information and poor management of fertiliser and pest and disease strategies. Farmers identified in focus group discussions their interest in optimising fertiliser inputs and protecting soil quality – potential areas supporting adoption. The PIPA analysis highlighted target audiences for project findings as farmers, suppliers, government and agribusinesses. The project planned strategies to build capacity for each of these audiences and the project research team. Planning identified experimentation, demonstrations, sharing, education and information provision, improved communications, training and the establishment of networks as key strategies to facilitate capacity building and adoption of new soil and irrigation methods.

7.5.1 Capacity building of research and extension staff and farmers

Formal training of research partners, extension staff and farmers in value chains, livelihoods analysis and soil and irrigation research and farming methods were conducted over four years and 17 workshops (Table 25). Overall, 30% of the research and extension staff participating in the workshops were women.

<u>Value chains and Livelihoods research training</u> - Training workshops on Value Chains, Livelihoods and qualitative research methodologies were delivered by Associate Professor Laurence Bonney, Dr Gomathy Palaniappan in Lao PDR and Dr Stephen Ives and Dr Ann Starasts in Cambodia. Workshops included intensive field training activities in data collection and a suite of pilot surveying, focus group discussions, qualitative research methods, interviewing and resource planning exercises. In addition to training, participants became familiar with the project goals and processes, and contributed to collaborative planning and discussions. Workshop evaluations indicated that the workshops successfully increased participants' knowledge of value chains and livelihoods and research. Participants in Cambodia indicated they would like further training in Livelihoods and research methodologies because of its high importance in a community's ability to adopt and make changes.

<u>Soil and irrigation training</u> - Training workshops on field Experimental Design and Implementation (Figure 36) facilitated by Mr John McPhee, Dr Alice Melland and Dr Jasim Uddin successfully increased the understanding of principles of experimental design, site characterisation, record keeping, health and safety, and project-specific experimental layouts and treatment options for most participants. Participants also became familiar with the project goals and needs. Staff working on project ASEM 2012/081 also attended the workshops. Soil and Irrigation workshops were facilitated by Robert Hoogers (Project ASEM/2012/081) and provided theory and practical knowledge sharing on soil and irrigation as well as opportunities to network across the research teams. At the soil and irrigation workshops, there was a mix of farmers and professional/technical staff from various organisations associated with the project. A Field Experimentation workshop

facilitated by Mr John McPhee and Dr Jochen Eberahrd covered data collection and collation, experimental layout, interpretation of irrigation system performance data and other aspects related to field experiments. In Cambodia, training of research staff in irrigation nomograph use led to research partners feeling confident to train extension staff.

Figure 36. Experimental Design Workshop in Pakse, Champasak province, Lao PDR, 17/06/2016 Photographer John McPhee

Table 25. Training workshops delivered by Australian partners for in-country project staff and farmers. *ASEM indicates that staff from ASEM 2012/081 also participated.

Date	Location	Topic	Participants (includes facilitators)
June 2016	Vientiane Pakse Phnom Penh	Experimental design and implementation Health and safety	21 (6 female) 14 (1 female) 10 (1 female) *ASEM
Nov 2016	Vientiane	Value Chain research Livelihoods frameworks Interviewing, focus group discussions, qualitative research	21 (6 female)
Dec 2016	Phnom Penh Kampot	Value Chain research Livelihoods frameworks Interviewing, focus group discussions, qualitative research	8 (2 female) *ASEM
Dec 2016	Vientiane Phnom Penh	Soil and irrigation Project engagement with staff	15 (4 female) 17 (2 female) *ASEM
Oct 2017	Vientiane	Qualitative research methods; interview skills, focus group discussions	10 (4 female)
Nov 2017	Paksong	Data collection and collation, experimental layout, interpretation, irrigation systems	7 (0 female)

Date	Location	Topic	Participants (includes facilitators)
May 2018	Kampot Siem Reap Champasak Vientiane	Soil and irrigation	30 (16 female) 30 (15 female) 13 (2 female) 15 (4 female) *ASEM
Feb 2020	Kampot Phnom Penh Vientiane	Irrigation scheduling, Daily application tables, Nomograph	6 (2 female) 10 (3 female) 4 (1 female)
Total			231 (69 female)

Informal capacity building occurred throughout the project. Partners in Lao PDR and Cambodia received support during every visit from the Australian side to increase their capacity to implement research activities, extract key messages from research data and practise problem-solving within research activities but also while interacting with farmers (Figure 37, Figure 38). This included Objective 3 and 4 Australian staff providing informal training to CARDI team members on soil pH, liming and irrigation management.

Australian research partners interacted via email on a regular basis with project partners from Cambodia and Lao research organisations to discuss results from surveys, replicated trials and demonstrations and field day discussions. This has included in some cases providing detailed written demonstration on how to analyse data (Lao PDR partners). Support was also provided in person and via email for some partners for presenting results of demonstration and trial sites in report formats.

ACIAR Launch funding was used in 2019 to bring four Lao and Cambodian project team members from our project and four Lao, Cambodian and Australian team members from related ASEM and CSE projects to present posters at TropAG2019 in Brisbane which was attended by 820 delegates spanning 43 countries. The abstracts were subsequently published in the open source Proceedings journal. The conference participation facilitated knowledge exchange and provided delegates the opportunity to learn about emerging research and development underway in tropical agricultural globally. The funding also enabled a workshop at USQ in Toowoomba when key extension messages were identified and technical publications in English, Khmer and Lao were planned and initiated. Authorship of publications by the project's researchers will enhance their publication records, capacity and reputation. Further details in Melland et al. (2019) Launch Fund Report SMCN2014088.

Ms Xiong (NUoL) was short-listed for an Australia Award PhD scholarship in 2019 to work with Dr Gomathy Palaniappan at the University of Queensland. That application was ultimately not successful, however, Ms Xiong has since applied for a John Allwright Fellowship in 2020.

In considering the capacities of project staff to facilitate ongoing learning and scale out with project and other villages, train the trainer workshops and 1 on 1 training were planned. In Cambodia, COVID restrictions also limited opportunities for planned 1on1 sessions with farmer leaders, input suppliers and PDA staff to discuss and identify future ongoing roles in supporting ongoing learning and adoption within communities and identify their capacity and training needs. However due to COVID restrictions and time limitations a full understanding of training needs was not identified and further training was not undertaken.

Figure 37. Interpretation of trial results and extracting key messages from research data during the annual project meeting at HRC, Vientiane, Lao PDR,17/10/2019. Photographer Phaythoune Mounsena

Figure 38. Hands-on discussion between farmer and extension officer in Siem Reap province, Cambodia, 05/04/2019. Photographer Jochen Eberhard

7.5.2 Constraints and opportunities for technical adoption

Constraints

Financial constraints - Initial socio-economic research indicated that low levels of education, a strong reliance for some on cash flow associated with vegetable production, along with poor or no returns may limit smallholders' ability to adopt new practices. Most farmers used their own money to fund vegetable inputs which potentially is the major limitation for adoption of new strategies. In both Lao PDR and Cambodia, some families accessed microfinance to pay for family consumption. In Lao PDR vegetable collectors practised informal lending during harvest, in return for the farmers' produce. Informal lending and borrowing are commonly used by farmers for various reasons including sharing of risk, long-term relationships and trust.

Education, information and networks - Farmers' education levels and small networks may limit their ability to be exposed to and understand extension and training information, making field-based events important. In Cambodia, farmers indicated limited sourcing of information from beyond their family or village; some household members did not often communicate beyond their family networks (Table 26). Similarly, in Lao PDR most farmers relied on personal experience and informal networks (family, friends, and colleagues) to meet their information needs. Although in the Focus Group Discussions farmers in Cambodia indicated they received information about soil management and irrigation from the PDA (including how to apply fertiliser and recommendations for chemical and organic fertiliser as well as irrigation frequency depending on the weather), farmers also suggested they lacked information on soil management and irrigation practices in relation to vegetables. This was echoed by participants in Lao Focus Discussion Groups. Other topics suggested by Lao farmers from Pakxapkao village (Palaniappan et al., 2018) were soil preparation and improvement, fertiliser application methods, pest and disease management, soil analysis and green houses to grow vegetables in the rainy season.

Table 26. Farmers approaches to sourcing information about vegetable production in Cambodia

	Koun Sat	Trapeang Chrey	Prey Ben	Ta Trav	Popis
Plan ahead vegetable crops	50%	50%	17%	50%	50%
Consult others about vegetable growing	96%	93%	89%	93%	90%
Who do you consult?	Family members 96%	Family members 100%	Family members 94%	Family members 100%	Family members

Opportunities

Farmer training (previous) - Many farmers had attended training (34-60% in Cambodia in topics such as vegetable production and fertilisers, 10-70% in Lao PDR) and varying percentages were prepared to trial and adopt new technologies (ranging from 4% of women in one village in Lao PDR to over 50% of participants in another village in Cambodia). Most previous fertiliser and irrigation training was related to rice production. Attendance at previous field days was 3-21% and 20-67% of participants had recently learnt new farming practices. Between 30 and 72% of participants were prepared to trial new soil or irrigation practices (Table 27).

Table 27. Past practice changes and attitudes in Cambodia

	Koun Sat	Trapeang Chrey	Prey Ben	Ta Trav	Popis
Tried new farm practices	17%	7%	17%	28%	25%
New practices	Fertiliser Mechanical Land preparation	New variety	Fertiliser rates Technical	Fertiliser Irrigation Growing	Fertiliser Opportunity marketing
Will try new soil practices	Yes 41% Wait 21% No 31%	Yes 50% Wait 21% No 29%	Yes – 50% Wait – 28% No – 17%	Yes 34% Wait 34% No 24%	Yes 30% Wait 33% No 23%

	Koun Sat	Trapeang Chrey	Prey Ben	Ta Trav	Popis
Reasons	Technical New experience High yield Interested but no material Good compare with traditional	High yield Reduce chemicals	Better product High profit If I understand Hydroponics	May change livelihood No available capital	Acknowledgement
Will try new irrigation practices	Yes 39% Wait 19% No 35%	Yes 50% Wait 14% No 36%	Yes 72% Wait 28%	Yes 41% Wait 41% No 17%	Yes 40% Wait 47% No 13%
Reasons	Save time, labour No money	Save time, water labour	Yield, profit Save water, time and labour	Save time, labour No capital	Save time, labour No money

Information transfer - Access to information about new soil and irrigation management practices will be a facilitating factor conducive to assisting technology adoption. Farmer Focus group discussions at Siem Reap field days in 2018 identified that more than 78% of farmers received information from AGRISUD about lime, fertiliser, irrigating and vegetable packaging, postharvest and contract farming (Figure 39). The second most common information source for farmers in the project (13%) was CARDI through experimenting on application of lime and fertiliser. Finally more than 4% indicated that ADDA and other NGOs, were sources of information in areas such as crop mulching, prevention of climate change effects, soil erosion and pest management. In Cambodia in Kampot province there are many NGOs and other partners with a role in developing agriculture, but these NGO and other partners did not have programs educating farmers about applying lime on vegetable cropping systems.

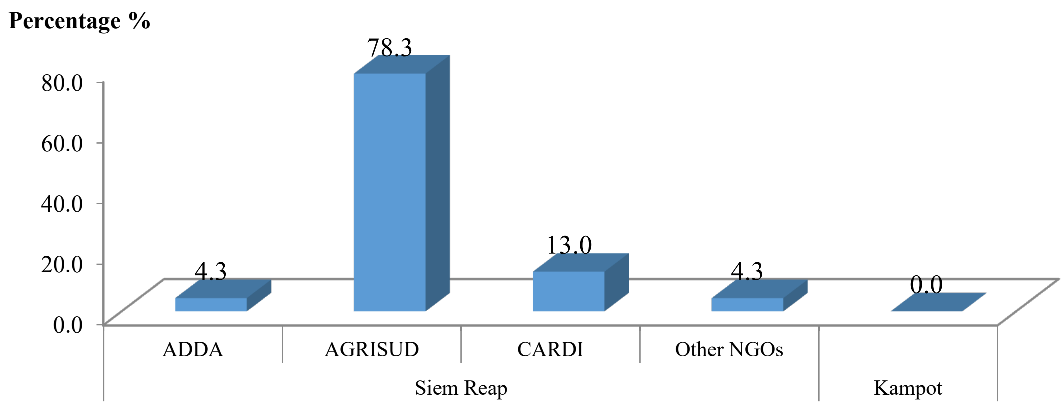

Figure 39. Sources of agricultural technical information, Cambodia Farmer Focus Group Data

Farmer feedback – During farmer field days demonstrating trials about the application of lime, fertiliser and irrigation practices in both provinces, Siem Reap and Kampot, the Socio-Economic team conducted interviews with farmers and focus group discussions. Farmers in the focus group discussions firstly believed the project should provide technical information about vegetable production (Figure 40) especially in the fertiliser-pest applications, along with irrigation information and vegetable packaging. They suggested that vegetable production was on soil that is increasingly acid (pH under 7). They believed the increasingly acid soil was caused by farmers using nitrogen over the recommendation rate and the nitrogen modifying to compounds such as NO_3^-, NH_4^+ which react in the soil, and increase the acidity of soil. More than 30% in Siem Reap and more than 40% in Kampot province indicated that this was a problem.

Secondly farmers suggested that they wished to optimise fertiliser application using appropriate recommendation rates for their soil types. The baseline survey during March 2017 identified that some farmers used more than 500 kg/ha of fertiliser on average in three villages in Kampot province, and more than 600 kg/ha on average in two villages in Siem Reap province. Fertiliser application above the recommended rate creates more expenses through input costs, reducing profits for the household family.The third factor farmers suggested in discussions was for information on techniques of vegetable growing in relation to pest control and irrigation systems. Currently for irrigation, the gravity method of irrigation, used by farmers in Koun Sat villages on sandy soils uses large amounts of water.

In summary financial constraints are a factor potentially limiting adoption, and availability and awareness of information sources about vegetable nutrition, irrigation and pest control is limited. Attendance at training can be problematic especially for male farm workers who work off farm, but participants are interested in learning, and many have good reasons why they are interested to try new soil and irrigation practices.

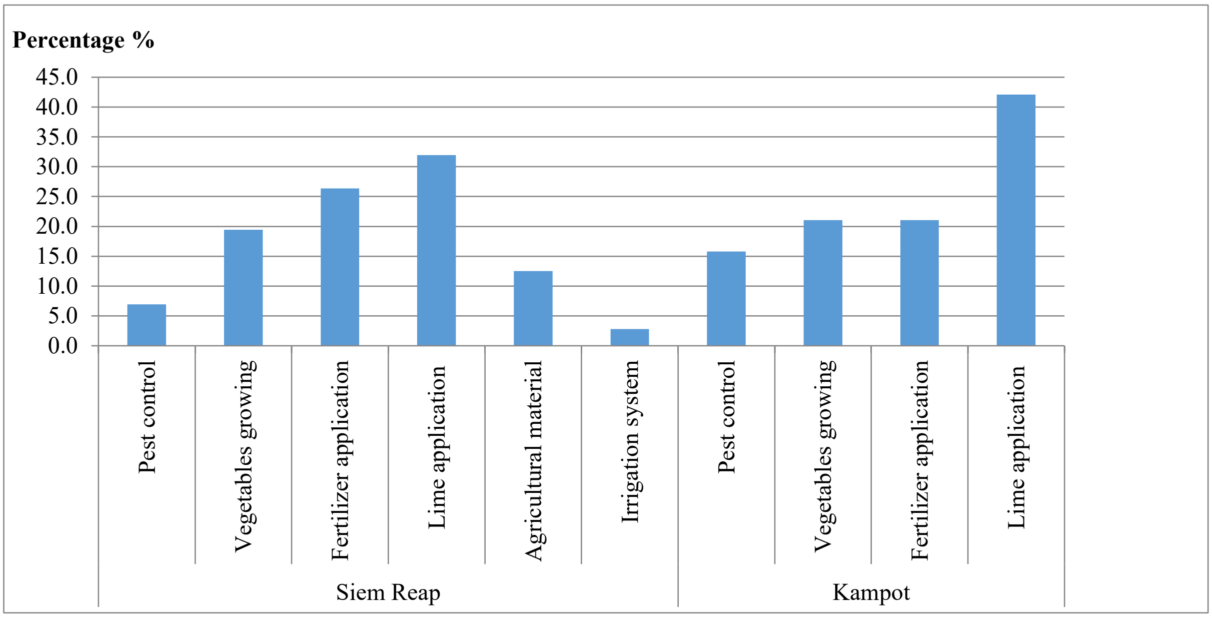

Figure 40. Farmers' information needs (Cambodia Focus Group Discussions)

7.5.3 Extension products and delivery to smallholder vegetable farmers and their suppliers

Extension activities include establishing demonstration sites, field days, information products, and a network of support for the vegetable industry.

In Cambodia, seventeen field days (Table 28) demonstrated and discussed lime application, fertiliser recommendation rates and irrigation strategies across 8 villages (including 3 non-project villages). Each field day included focus group discussions and some 1 on 1 interviews with farmers to identify attitudes, issues in relation to adoption and information needs. Farmer participants were mainly female (Siem Reap 87%, Kampot, 77%). Discussions held at events in 2018 and 2019 revealed that agricultural lime is unavailable to farmers (38% believe that only lime used in construction is on the market and the product is too far away for them to purchase). At the conclusion of the project, Farmer Notes were distributed and explained to farmers from 13 villages, including 8 that were not involved in the project activities. Across these field days and training events there were over 700 farmer attendees.

Information for farmers about methods of applying lime and fertilisers and irrigation on vegetables was provided to farmers attending field days at the site of farmer field demonstration trials in the target area of the project. The numbers of male and female farmers attending farmer field days shows strong differences, with a much higher percentage of attendees being women than men (Table 29 and Table 30). Male farmers often have other work off farm, earning higher income compared with on farm incomes. Participants at farmer field day demonstrations included farmer vegetable growers and market suppliers, representatives from companies (including Malysan Group and Rainbow Agro-sciences Group), NGOs (including Agricultural Development Denmark Asia (ADDA)) and CARDI staff.

In Lao PDR, value chain network analysis in Nasala village with 8 farmers (4 male and 4 female) and Pakxapkao with 10 farmers (5 male and 5 female) identified traders to be the most important actor in the value chain followed by organic manure suppliers, retail shopkeepers and neighbours. Traders sell produce in the market, organic suppliers provided organic manure and shopkeepers recommend fertilisers. Nine field days or workshops (Table 28) were conducted by NAFRI, HRC and CADC project staff as well as other relevant experts and were attended by 171 stakeholders comprising 118 farmers, 47 research and extension (PAFO, DAFO) staff and six input suppliers across seven villages. Topics covered included pest and disease, irrigation, supplier registration requirements, lime, organic matter and fertiliser management. At the extension events, the median percentage of attendees that were female was 31%.

Farmer Discussions - Discussions assisted the incorporation of community-led perspectives (Gustafson et al, 2018) and participatory knowledge systems (Vermeulen & Wynter, 2014) into the planning. In Cambodia, these highlighted that:

- Farmers had difficulty accessing lime (many believing only construction lime is available) and products are too far away for them to purchase.
- a need for technical information on how to grow vegetables (30% in Siem Reap and 45% in Kampot). Quality information is a key driver for farmers to assess their own ability to adopt (Le Dang, Nuberg & Bruwer, 2014).
- Farmers are interested in vegetable production methods that minimise impacts on their health through low chemical use and sustainably maximise use of their irrigation water.

In Lao PDR, farmer focus group discussions highlighted that:

- There is limited advice available on soil management, including those with low chemical fertiliser use
- There is a need for appropriate irrigation techniques.

Products - Table 31 lists extension and training products developed by SMCN2014/088 and target audiences. The vegetable growing farmer note has been distributed as per Table 32.

Input Suppliers – Extension activities with input suppliers participating in the project in Cambodia included (i) individual discussions highlighting lime application benefits in vegetable soils and recommended NPK fertilisers and (ii) distribution of the vegetable production farmer note. (iii) Letters outlining Objective 1 recommendations in relation to a possible role for supply shops to store and provide technical information about products and vegetable production and new lime and irrigation strategies were drafted. (iv) Further one on one training for suppliers about this information role, lime, NPK fertilisers and irrigation information were planned but were unable to occur due to COVID restrictions.

Table 28. Field days and farmer training workshops in Kampot and Siem Reap provinces in Cambodia, and in Vientiane and Champasak provinces in Lao PDR. The total number of attendees, and the number of attendees who were female where known, is indicated.

Field days Activity 2.5	Province	Attendees and village
2017		
Initial field day & survey (6-11 February)	Kampot	11 farmers in Chhouk (9 women)
Initial field day & survey (12-17 March)	Siem Reap	14 farmers in Ta Trav (10 women)
2018		
Field days before vegetable planting (5-10 March, 22-23 March)	Kampot	20 farmers in Trapeang Chrey village 35 farmers in Prey Ben village 38 farmers in Koun Sat village
Field days before vegetable planting (5-10 March)	Siem Reap	40 farmers in Ta Trav village Kantreng commune Prasat Bakong district
Workshop - Pest, disease & soil quality (22-24, 26-28 March)	Vientiane Champasak	11 (4 female) in Pakxapkao village 10 (8 female) in Nasala village 15 (6 female) in Huaha village 13 (3 female) in Thongset village 12 (1 female) in Katoud village
Field days during vegetable harvesting (21-22 May)	Kampot	53 farmers in Prey Ben village
Field days during vegetable harvesting (8-10 April, 2-5 June)	Siem Reap	45 farmers in Ta Trav village Kantreng commune Prasat Bakong district 62 farmers in Popis village Krabey Reil commune Tuek Vil Research Station
Workshop – soil water retention (1 November)	Vientiane	4 farmers (1 female) and 1 male staff from mix of project sites (Pakxapkao, Nongboua and Donley villages and Champasak research station)
2019		
Field days (3) (14-18 February)	Kampot Siem Reap	35 farmers in Ta Trav village Kantreng commune Prasat Bakong district 47 farmers in Prey Ben village, Sat Pong commune, Chhouk district, 49 farmers in Totea village, Krabey Riel commune Female attendees (Siem Reap 87%, Kampot, 77%)
Field day – lime & fertiliser (29 March)	Vientiane	19 farmers, 20 staff (NUoL, PAFO, DAFO, CADC, USQ, UTas), 3 students (13 female) in Pakxapkao village
2020		
Field days (18-21, 26-28 February)	Kampot Siem Reap	11 farmers (7 female) Prey Chheuneang, Sat Pong commune, Chhouk district 24 farmers (16 female) Beng village, Krabey Riel commune, Ta Trav village, Kantrong commune
Workshop – lime, organic matter, irrigation, agrochemical regulations (13, 20 February)	Vientiane Champasak	24 farmers (16 female) from Nasala, Pakxapkao and Huaha villages, 11 staff (4 female)(NUoL, HRC, MAF, PAFO, DAFO) 10 farmers (2 female) from Thongset and Donley villages, 6 input suppliers (2 female), 12 staff (3 female)(NUoL, HRC, MAF, PAFO, DAFO)
Farmer note distribution & explanation to individuals & groups (May-Jun)	Kampot Siem Reap	245 farmers, 15 suppliers, 13 villages (including 8 villages from outside the project activities)

Table 29. Percentage % of male and female participants involved in activities of the project

Villages	Popis	Kok Dong	Ta Trav	Trapeang Thnol	Prey Ben
Male	8.3	5.9	17.2	18.2	25.0
Female	91.7	94.1	82.8	81.8	75.0
Average age	46	45	44	35	44

Table 30. Farmers involved in field days in Cambodia

Provinces	Schedule planted	Year 2018	Year 2019	Year 2020
Kampot	Before planted	93/female 26	47/female 16	11/female 7
	Harvested	53/female 32		
Siem Reap	Before planted	45/female 27	35/female 24	24/female16
	Harvested	107/female 94		
Total farmers	B/H	298/female 179	82/female 40	35/female 21

Table 31. Extension and training products developed by SMCN2014/088 and their target audiences

Extension products for farmers

Factsheets and Farmer Notes

- ACIAR SMCN 2014 088 (2018a) Applying lime in vegetables. Factsheet, Cambodia
- ACIAR SMCN 2014 088 (2018b) Irrigating vegetables. Factsheet Cambodia
- ACIAR SMCN 2014 088 (2020a) Vegetable growing-fertiliser, lime and irrigation Farmer Note Cambodia
- ACIAR SMCN 2014 088 (2020b) Vegetable growing-fertiliser, lime and irrigation Farmer Note Lao PDR (Lao, English)
- ACIAR SMCN 2014 088 (2020i) Irrigating vegetables. Farmer Note Cambodia (English, Khmer)
- ACIAR SMCN 2014 088 (2020j) Lime and fertilizer application for leafy vegetables on sandy acid soils (Prey Khmer and Prateah Lang soil groups). Farmer Note. CARDI (Khmer)
- ACIAR SMCN 2014 088 (2020k) Irrigation management for short, medium and long leafy vegetable crops in Siem Reap and Kampot provinces. Farmer Note. CARDI (Khmer)

Videos and presentations

- Sisouvanh, P. & Xiong, M. (2020) Irrigation, fertiliser and lime application videos
  - https://www.youtube.com/watch?v=2kfl4ycuXZw&t=260s (Lao)
  - https://www.youtube.com/watch?v=Agez_ubnyRw&t=31s (Lao)
  - https://www.youtube.com/watch?v=bJvNV-7FPN4&t=60s (Lao)

Decision support tools

- ACIAR SMCN 2014 088 (2020g) Lime calculator. Android App. (Khmer, English, Lao) A simple smartphone app that calculates the appropriate application rate of lime depending on soil pH, soil texture, organic matter content and type of lime. Google Play “Lime Requirement Calculator” https://play.google.com/store/apps/details?id=com.lime_requirement_calc.app

Extension products for farmers

Training products for extension staff

Technical Notes

- ACIAR SMCN 2014 088 (2020c) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Technical Note (Khmer, English)
- ACIAR SMCN 2014 088 (2020d) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Technical Note (Lao, English)
- ACIAR SMCN 2014 088 (2019a) Daily application tables for irrigation of leafy vegetables in Cambodia. Technical Note (Khmer, English)
- ACIAR SMCN 2014 088 (2019b) Daily application tables for irrigation of leafy vegetables in Lao PDR. Technical Note (Lao, English)

Presentations

- ACIAR SMCN 2014 088 (2020e) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Training presentation (Khmer, English- narrated)
- ACIAR SMCN 2014 088 (2020f) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Training presentation (Lao, English – narrated)

Research assistance products for research staff

Technical Notes

- ACIAR SMCN 2014 088 (2020h) Irrigation nomograph master. Technical Note (English-Khmer, English-Lao)

Decision support tools

- ACIAR SMCN 2014 088 (2018c) Distribution Uniformity-Infiltration Calculator – MS Excel Technical Aid for calculating irrigation distribution uniformity for hand-held hose, sprinklers and watering can irrigation systems, and soil infiltration rates.
- ACIAR SMCN 2014 088 (2018d) Etc Irrigation Calculator. Siem Reap example. MS Excel Technical Aid for preparing district-based irrigation schedules for vegetable crops in Cambodia using FAO-equations for crop water demand.

Table 32. Farmer note distribution, explanation and clarification with farmers, suppliers and extension partners and stakeholders in Cambodia

Provinces	Districts	Communes	Villages	Sample /Male	Sample/ Female	Total Samples
Kampot	Chhuk	Sat Pong	Prey Chheneang	8	11	19
			Prey Ben	8	10	18
		Chhuk	Trapeang Chrey	7	9	16
	Tuk Chhou	Koun Sat	Koun Sat	6	18	24
			Trapeng Pring	4	16	20
			Bos Nhing	6	7	13
Siem Reap		Kon Trang	Ta Trav	13	30	43

Provinces	Districts	Communes	Villages	Sample /Male	Sample/ Female	Total Samples
	Prasat Bakong		Trapeang Thnol	6	15	21
	Siem Reap town	Krabey Real	Krasang	1	9	10
			Popis	7	13	20
			Kouk Dong	2	8	10
			Beng	2	11	13
	Puok	Samrong Year	Samrong Year	4	14	18
Total	5	6	11	74	171	245
Others						
Suppliers in Kampot						5
Suppliers in Siem Reap						10
PDA, Kampot						15
PDA, Siem Reap						20
Total						295

Scale out plans – The project has engaged in Cambodia with over 700 farmers in 13 village locations. Discussions were held through the life of the project with other local project staff PADEE, AGRISUD, MEANCHEY KONSAT Community Centre project, Angkor Salad Project, CDRI, and ADDA, agribusiness organisations and institutions including Maly san (Agribusiness products), Rainbow Agro-sciences Group, and the World Vegetable Centre during 2018, 2019 and 2020. Invitations were extended to field days held during this time. The vegetable production Farmer Note was distributed to these organisations in June 2020 and a letter outlining their potential role to help spread the learnings about lime, recommended NPK fertilisers and irrigation practices was drafted and sent for the project team to distribute to organisations which could support scale out and a legacy for the project. The vegetable production Farmer Notes have been published online on the CARDI Extension Web platform.

Distribution of the Farmer Note more widely to IFAD, COSOP, and IDE, and engagement with other projects e.g. Cambodia Agricultural Value Chain Program, Lao-Australia Development Learning Facility, and institutions (eg Royal University of Cambodia and Battambang University) was not achieved due to time limitations, however may be achieved beyond the project timeframe.

Training and capacity building for Cambodian and Lao research and extension staff occurred in irrigation scheduling strategies in February 2020 in order that staff will be confident to provide future training to farmer leaders and interested farmers as part of their future roles. Further capacity building especially with extension staff was planned to build understanding and skill in developing networks and facilitating innovation and resourcing communities, however due to restrictions, did not occur.

Scaling of the project’s findings can further occur through use of social media to promote vegetable production recommendations (through farmer facebook groups) and irrigation strategies (promotion of video on Youtube). This has not fully occurred to date due to time restrictions. Publication of conference publications in ‘Proceedings’ has occurred and in peer reviewed journals is planned to ensure project findings are shared in established scientific and extension practice networks.

7.5.4 Social, environmental and financial costs and benefits of technology adoption

Although vegetable production in Cambodia and Lao PDR is expanding, increases in production are insufficient to meet current consumer demand with domestic production of vegetables still heavily supplemented by imports. The ability to produce more vegetables on small scale farms due to more efficient use of fertiliser and irrigation is therefore potentially a significant benefit from adopting project findings. This could help grow the vegetable industries in both countries and meet market needs.

This project has demonstrated that using lime in vegetable soils has the potential to increase yields by up to 100%. It has demonstrated that with recommended fertilisers and rates vegetable yields and profits potentially are higher. It has highlighted the importance of irrigation scheduling and understanding crop water demands in order to efficiently manage water resources in vegetables, resulting in financial rewards, less labour use, and potentially better crops. Irrigation strategies developed in this project can result in savings in excess of 50% of water and labour. Growers could therefore be producing 2-3 times more leafy vegetables on the same area of land and using less water.

Costs of adopting irrigation and lime strategies are labour, inputs and finance. Background information on these factors is included below.

Labour

Most villages in Cambodia had on average 2 family members working in vegetable production. Most participants from all villages did not hire additional labour for vegetable production beyond household members (except in TaTrav village where less than 20% of participants hired additional labour and mostly for heavy work). Labour is estimated to cost 20000-25000 Riel ($7-8.50 AUD) per day (for 8 hours) and is usually hired for full or half day periods. There has been no indication that labour availability is a limitation with respect to applying lime, however purchasing lime for some farming families from the supply shops could be difficult depending on the bag size, distance to supply shop and availability of transport. Recommended irrigation practices should save labour inputs.

Finance

In Cambodia, most farmers used their own funds to grow vegetables rather than borrowing funds. Table 33 shows the low numbers of farmers borrowing money for farm inputs and those who used microfinance. The interest rate payments when borrowing from microfinance varies from 1.6 – 3% in Kampot, and 1.2 – 4.4%, in Siem Riep province. A small number of farmers borrow from microfinance to support their family's consumption, family events and study.

Table 33. Investment source for vegetable farming expenses

Investment source of farmer	Village: Koun Sat	Trapeang Chrey	Prey Ben	Ta Trav	Popis
Own investment field productivities	27	14	17	23	28
Borrow investment from microfinance	2		1	3	2
Borrow investment Expend out farm	2	2	4	6	4
Total farmers surveyed	29	14	18	29	30

Profitability of vegetable farms

Cambodia - Profits from farm enterprises are listed in Table 34. Participants were asked their perception of the income they received from vegetables. Most participants in Koun

Sat (as an example) considered their vegetable profits (on average $956) as medium. They attribute this to price, volume of vegetables and short maturity. Thirty one percent of participants indicated low or no profits which they attributed to household use, low prices, low yields and insufficient land (Table 35). One third to two thirds of farmers in participating villages earned extra income off farm. This included having a business, having livestock, growing vegetables in the dry season, labouring or factory work.

Table 34. Profits (USD) from farming and other activities in Cambodia. Note – vegetable income is for only 4-5 months. Other business and labour income is for 12 months.

Income ($)

Villages	Vegetable	Livestock	Rice	Business	Labour	Other
Kunsat	956	923	208	393	550	621
Trapeang chhrey	199	750	300	381	1125	813
Preypen	287	547	255	1250	707	465
Tatrav	776		400	75	1230	1800
Porpeis	294	750	269	75	2300	674
Average income	502	742	286	435	1182	875

Percentage Indicated Profit for vegetables production

Villages	Higher profit	Medium profit	Low profit	Non profit
Kunsat	3.4	65.5	10.3	20.7
Trapeangchhrey	21.4	42.9	21.4	14.3
Preypen	0.0	66.7	33.3	0.0
Tatrav	3.4	58.6	34.5	3.4
Porpeis	0.0	66.7	33.3	0.0

Table 35. Profitability and reasons; Koun Sat village, Cambodia (Cambodia Livelihoods report)

Koun Sat – profitability of vegetable growing (E.4) (n=29)			
Profitability	**Percentage**	**Profit range (Cambodian Riel)**	**Reason**
High	3	3,000,000	High price
Medium	66	100,000 – 6,192,000	Sell at high price Keep for consumption Short maturity Grow a lot of vegetables Low price Expenditure
Low	10	1,000,000 – 2,075,000	Low price (Use) for household
Not profitable	21	400,000 – 1,699,000	(Sell) vegetables cheaply Eat vegetables themselves Low yield Low profit Not enough land

Financial costs and benefits from adoption of findings

Research teams from Cambodia undertook economic analyses and representation of the financial costs and benefits of adoption of lime, recommended fertiliser rates and irrigation strategies. This is based on average trial data findings from 12 demonstration sites across Kampot and Siem Reap provinces in 2019. Table 36 shows higher profit and income on average when lime is applied to vegetable soils at a rate of 2 t/ha in Siem Reap sites and 1 t/ha in Kampot sites. Table 37 (a and b) shows that economic analysis of recommended fertiliser inputs and irrigation strategies demonstrates increasing profits with lime application and that the recommended fertiliser rate (which may be a reduction in fertiliser rate and input cost) can produce higher (or similar) yields and profits. Similarly, at a demonstration site near Paksong, Champasak Province in Lao PDR, an economic assessment of costs and revenue showed that using fertiliser with balanced NPK at rates aimed at meeting higher yield crop demand, the yield per bed doubled compared with farmer practice and the extra revenue was more than enough to cover the extra fertiliser used (Figure 22, Section 7.3.8).

Table 36. Economic analysis of lime application, response, input costs and profit for a) Siem Reap and b) Kampot provinces. All monetary values are in USD

(a) Siem Reap province, Bokchoy. Average from four farmer sites

Treat-ment	Lime rate (t/ha)	Fertiliser rate (kg/ha)	Yield (t/ha)	Price vegetable ($/kg)	Input cost ($/ha)			Total input cost ($/ha)	Total income ($/ha)	Profit ($/ha)
					Labour and other materials cost ($/ha)	Lime cost ($/ha)	Fertiliser cost ($/ha)			
L1	0.0	1,416.	24.9	0.5	1,866	-	935	2,801	12,450	9,648
L2	0.5		28.3			300		3,101	14,150	11,048
L3	1.0		35.3			600		3,401	17,650	14,248
L4	2.0		40.0			1,200		4,001	20,000	15,998

(b) Kampot province, Green Mustard. Average from three farmer sites

Treat-ment	lime rate (t/ha)	Fertilizer rate (kg/ha)	Yield (t/ha)	Price vegetable ($/kg)	Input cost ($/ha)			Total input cost ($/ha)	Total income ($/ha)	Profit ($/ha)
					Labour and other materials cost ($/ha)	Lime cost ($/ha)	Fertilizer cost ($/ha)			
L1	0.0	1,083	30.1	0.425	1,866	-	596	2,462	12,807	10,345
L2	0.5		32.8			300		2,762	13,947	11,185
L3	1.0		34.8			600		3,062	14,789	11,727
L4	2.0		32.6			1,200		3,662	13,863	10,201

Table 37. Economic analysis of lime, recommended fertiliser and irrigation strategies – response, input costs and profit, for a) Siem Reap and b) Kampot provinces. All monetary values are in USD

(a) Siem Reap Province, Bokchoy (Average from two farmer sites)

Treat-ment	lime rate (t/ha)	Fertilizer rate (kg/ha)	Yield (t/ha)	Price vegetable ($/kg)	Input cost ($/ha)			Total input cost ($/ha)	Total income ($/ha)	Profit ($/ha)
					Labour and other materials cost ($/ha)	Lime cost ($/ha)	Fertilizer cost ($/ha)			
T1	–	1,417	15.7	0.5	1,866	–	935	2,801	7,850	5,049
T2	2		20.5			1,200		4,001	10,250	6,249
T3	–	1,333	18.7			–	760	2,626	9,350	6,724
T4	2		24.4			1,200		3,826	12,200	8,374
T5	2		24.6						12,300	8,474*

* T5 with irrigation based on crop demand. Reduced water demand and labour not included

(b) Kampot Province, Green Mustard (Average from three farmer sites)

Treat-	Input cost ($/ha)	Profit ($/ha)

ment	lime rate (t/ha)	Fertilizer rate (kg/ha)	Yield (t/ha)	Price vegetable ($/kg)	Labour and other materials cost ($/ha)	Lime cost ($/ha)	Fertilizer cost ($/ha)	Total input cost ($/ha)	Total income ($/ha)	
T1	–	1,083	26.2	0.425	1,866	–	596	2,462	11,135	8,673
T2	2		29.2			1,200		3,662	12,410	8,748
T3	–	1,333	26.2			–	733	2,599	11,135	8,536
T4	2		30.6*			1,200		3,799	13,005	9,206
T5	2		30.2						12,835	9,036*

* T5 with irrigation based on crop demand. Reduced water demand and labour not included

Social factors influencing adoption potential

Cambodia - Limited participation in some local village networks may mean less opportunities for villages to share experiences and discuss new farming practices. Approximately 10 – 45% of farmer participants in the Livelihoods survey indicated they only knew a few other people in their village, whilst farmers indicated they communicated with others beyond the family only occasionally (69 - 90% farmers). Similarly for some participants there was limited participation in local farmer groups (where potentially they could learn about and discuss new farming practices). Approximately 14-57% of farmer participants in the Livelihoods survey were members of farmer groups (Table 38). Those who were not members of farmer groups indicated they had no information about the group, no invitation to participate in the groups, lack of time or no interest.

In Lao PDR, participant farmers indictaed that they will make changes if it works well for their neighbours and they believed in expert advice; if experts demonstrated innovative techniques, they would adopt willingly. Farmers from a farmer group in Paxapkao had good experiences in training and trialing of new techniques and had linkages with the Department of Extension, DAFO and PAFO.

Table 38. Participation in local groups

	Koun Sat	Trapeang	Ta Trav	Popis	Prey Ben
Participation in local group	41%	43%	14%	57%	50%
Spouse membership of local group	28%	29%	14%	53%	33%
Organisations	CIDAC PADEE GDA GIZ	CIDAC	Racha Helen Keller	Agrishot	Helen Keller Farmer group
Reasons for not participating in groups	No time No information No invitation	No information No interest	No time No information	No time No invitation	No time No information

Environmental benefits from technology adoption

Farmer discussions during 2018 field days had identified their concerns about the sustainability of their vegetable production system, especially from continued use of high rates of inorganic fertilisers, especially nitrogen. Farmers suggested that they were growing vegetables on increasingly acid soils which they suggest was caused by farmers using nitrogen higher than the recommended rate. More than 30% indicated in Siem Reap and more than 40% in Kampot province that this was a problem. Farmers therefore wanted to optimise their rates of fertiliser application The farming systems survey in March 2017 identifed that some farmers used more than 500 kg/ha on average in three villages in Kampot province, and more than 600 kg/ha average in two villages in Siem Reap province. Farmers irrigating in sandy soils using gravity methods identified high water consumption and losses and suggested this approach was not sustainable over a long period. Research in this project identified a range of irrigation strategies in crops from underwatering early in the crop stage to overwatering 150-200% through most of the growing season.

The farming practices and recommendations identified in this project include recommended fertiliser and lime rates in order that vegetable production is sustainably undertaken (and with increasing yields), and reducing risks from over-fertilising. The project has highlighted the importance of irrigation scheduling and understanding crop water demands in order to efficiently manage water resources in vegetables, yet still resulting in increasing profits, less labour use, and potentially better crops. Irrigation strategies developed in this project can result in savings in excess of 50% of water. Adopting the lime, fertiliser and irrigation practices recommended as a result of this project has environmental benefits of reducing the potential for water and nutrient losses in leaching and runoff and for greenhouse gas emission. It is important that these key messages are conveyed to farmers and project stakeholders.

7.5.5 Changes in attitude, knowledge, skills and practice of project participants

Field days, demonstrations, discussions and information products were designed and have contributed to building knowledge and understanding among project researchers, staff and project participants.

Farmers within villages participating in the project have had the opportunity to gain knowledge and skills in vegetable fertilising and irrigation strategies. In Cambodia, lime had largely been used in the project target area in non-crop activities such as aquaculture and building industries and was not used significantly within vegetable industries. Interest in the use of lime was highlighted throughout the project in farmer interviews at field days and demonstration trials during vegetable harvesting in Cambodia where farmers were very interested in the field experiments and achievements. This interest was also evidenced in discussion data listed in section 7.5.2 where at field days in 2018 and 2019, farmers were concerned that they did not know where to purchase agricultural lime products, however this information was collated and provided to farmers at field days in 2020 and in the distributed farmer note.

Following a relatively poor understanding of lime and its role in vegetable production on acid, sandy soils, project field days were attended by over 800 farmers. These farmers have now built their knowledge and understanding of lime and soil nutrition and basic irrigation strategies. In Lao PDR, farmers agreed that they will make changes if it worked well for their neighbours and will adopt practices if the technique has trialability, is productive and results in a better market price. Farmers have also had the opportunity to build their knowledge through questioning and clarification in discussions, for example, when Farmer Notes were distributed and explained to 245 farmers in 2020 in Cambodia in 13 villages. A number of other project operators, commercial businesses and NGOs also improved knowledge and understanding of the project outcomes through attending field days, project discussions and receiving and discussing farmer notes.

In addition, hands-on soil and irrigation workshop activities through the project have contributed to farmers, research and extension staff gaining confidence in identifying soil texture and calculating plant water requirements based on soil type, crop type and growth stages.

Input supplier knowledge and understanding about lime value and recommendations for nutrition and irrigation of vegetable soils was enhanced through individual discussions with project staff through the project period and when farmer notes were distributed and recommendations were individually explained by project team members in Cambodia (Table 32). Further summative assessments of improvements in farmer or input supplier knowledge and skills were not undertaken in 2020 across the project locations to finalise evaluation of the project due to COVID restrictions. Individual village data on attitudes to new lime, fertiliser and irrigation practices could be used to guide future activities targeted to further facilitate adoption. Capacity building activities with farmer leaders and extension staff in facilitation skills and future extension roles did not occur due to restrictions.

The initial farming systems survey of 120 farmers in Cambodia in 2017 identified that 30-50% were prepared to try new soil practices because they hoped to improve their yields, products and livelihoods. Almost forty to over seventy percent of farmers were prepared to try new irrigation practices because of potential savings in time, labour, water and money (Table 27). Farmer attitudes to lime that were identified through focus group discussion data (2018, 2019) from Siem Reap show that most farmer participants (more than 66%) believed that high yields occur when they apply lime, 2.6% believed that lime reduces improves disease incidence, 23.4% of farmers wanted to test lime to develop an opinion and 7% farmers believed that good quality vegetables prefer non-lime. Similar results were found in Kampot province. Evaluation data collected in 2020 from farmer participants identified very high interest in applying lime (Figure 41, Figure 42).

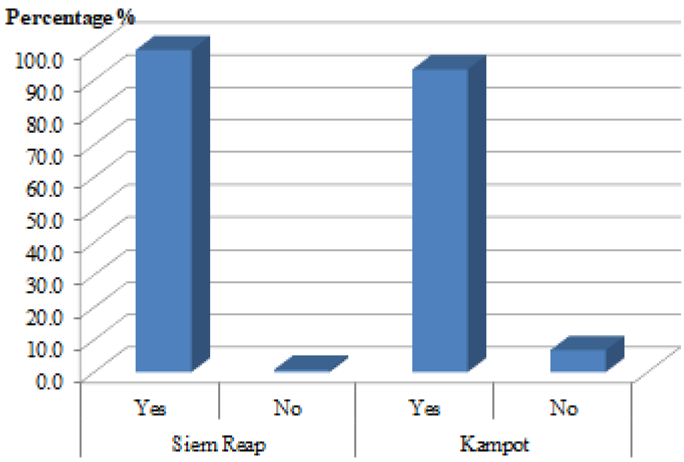

Figure 41. Farmer interest in applying lime in vegetables (2020)

As indicated, final evaluations of outcomes from this project did not occur due to COVID restrictions, however the following snapshot of data from three field days attended by 35 farmers in 2020 show that lime adoption in vegetables was widespread – 48.7% of Kampot farmers and 61.2% of Siem Reap farmers. Adoption of lime doubled within Siem Reap participating villages assessed and increased seven-fold within Kampot participating villages assessed (Figure 42). Extension evaluation comments on achievements are indicated in Table 39.

Although farmers have plans for adoption and have changed practices, in order for long term and confident changes to be made to farming systems there is a need for ongoing resourcing and advisory services. Input suppliers are now more aware about lime and soil nutrition needs for vegetable production. Following discussions with project staff, hopefully they are now aware of their potential role in providing information resources for farmers and their potential their role in communicating issues to experts. Other projects and NGO staff who have participated in the project have increased knowledge and skills, however there is significant scale-out work needed to extend project findings to a broader number of other projects and staff. In Lao PDR, the project team shared research findings at a vegetable forum and developed linkages with NGOs, PAFO and DAFO, small enterprises and seed companies, who have been identified as important stakeholders to scale out project findings. Meetings with the Ministry of Agriculture and Forestry were also held in Lao PDR to guide scale out activities through public extension.

The project team has built knowledge and skills. The extent to which they are able to continue resourcing vegetable producers in villages with information and support in their adoption of soil and irrigation practices is unknown due to future commitments. It is for this reason that further capacity building with the team is needed in future projects. Table 40 and Table 41 provide an indication (from project staff) of the level of interest in adoption of the project findings among villagers and extension staff.

Figure 42. Adoption of lime in vegetable cropping amongst Cambodian farmers participating in the SMCN 2014/088 project at the start and end (2020, n=35) of the project.

Table 39. Evaluation update for Cambodia in response to PIPA indicators

Evaluation of extension (2.6a)
ACIAR SMCN2014/088 Monitoring & Evaluation Framework

Indicator	Comments
KNOWLEDGE	
Farmers **assessed feasibility of practices** (20 per village; 100 non-project village)	Approximately 460 attendees at field days **inspected trials and assessed practices.**
ATTITUDES	
Farmers have a **plan to improve soil and irrigation management** (30 per village; 160 non-project village)	Field day discussions highlighted numbers of farmers who **believe new practices will improve or maintain yields** AND those who will **test practices.**
PRACTICES	
Farmers have **tested alternative practices** (20 per village; 100 non-project village)	
Farmers have **adopted new practices** (20 per village; 100 non-project village)	Discussions (February 2020) highlight an **increased demand and sales of lime** products and that some farmers were **trialling new irrigation practices.**
Extension/local service providers **encourage new practices** (60%)	PDA staff, suppliers, some NGO and project staff are aware of recommended practices and indicated they **will encourage these among vegetable farmers.**
Farmers, suppliers, private & government staff **participated in discussions** or receive **reports.** (150; 30 per village & >60% private/government staff)	**Discussions** with farmers, suppliers, NGO's, PDA and company staff – at field days, workshops and 1 on 1.

Table 40. Interest in adopting project findings – villages and staff Cambodia

Interest in adopting project findings - * some interest, ** good interest, *** very good interest				comments
Village or person	Trial/adopt lime	Trial/ adopt new irrigation practices	Trial/ adopt recommended NPK rates	
Kampot				
Chhouk				
Trapeang Chrey	*	*	*	
Prey Ben	***	*	**	
Koun Sat	**	*	**	1
Prey Chheuneang	*	*	*	
PDA staff in Kampot	***	**	***	
Siem Reap				
Ta Trav	***	**	***	1
Popis	***	**	**	1
Totea	***	*	**	
Beng	**	*	**	
PDA staff in Siem Reap	***	*	***	

Notes for future scaleout: 1 The project could start field experiments lime, fertiliser, and irrigation in neighbouring villages to project villages. The Koun Sat commune, Tuk Chhou district has a lot of villages as well Trapeng Pring and Bos Nhing villages grow many vegetables and have problems of acid soil and drought.

Table 41. Interest in adopting project findings – villages and staff (Laos) Note – Table is incomplete due to poor availability of information due to weather and restrictions. No data for Champasak province available.

Interest in adopting project findings - * some interest, ** good interest, ***very good interest			
Village or person	Trial / adopt lime	Trial / adopt new irrigation practices	Trial/adopt recommended NPK rates
Vientiane			
Pakxapkao	**		*
Huaha			
Thaxang	**	***	
Government staff in Vientiane	*		

8 Impacts

8.1 Scientific impacts – now and in 5 years

Project team members have consolidated their knowledge and skills in planning, undertaking research and extension, reporting and evaluation through their participation in the project. In particular:

Socio-economic team members have improved knowledge and skills in (i) livelihoods frameworks and their role in guiding community interventions and development projects, (ii) input supply chain research concepts, (iii) qualitative research data collection methodologies including interviewing skills, facilitating focus group discussions, case studies and resource mapping, and (iv) qualitative data analysis and reporting.

Soil and irrigation team members have built their expertise in undertaking research trials and collecting, analysing and reporting on these, and in extending results to farmers.

Team members have improved knowledge of the importance of lime; they have gained information resources regarding vegetable crop and soil nutrition and general irrigation strategies and benefits and some are trained in undertaking irrigation scheduling. It is hoped that the concepts of efficiencies in fertiliser and irrigation will be lasting scientific impacts that carry with the team to contribute to future sustainability of vegetable production.

8.2 Capacity impacts – now and in 5 years

8.2.1 Confidence knowledge and skills change

Capacity building approaches applied throughout the project will have impact beyond the project, extending to other aspects of the participants' research and extension activities.

Smallholders have gained knowledge and skills through participatory action research that will enhance their businesses and livelihoods, and through extension, those of their peers. Field days, information and discussions have enabled farmers to assess new practices and the impact on their own farming businesses in terms of labour, input costs and profits. These activities have contributed to building knowledge and confidence in decision making around adaptation of farming practices to enhance sustainability (see section 7.5.5).

Through their understanding of key contacts and various roles, and provision and explanation of information, input suppliers, other projects and NGOs who participated in the project have enhanced knowledge and capacity in terms of accessing and sharing information about vegetable production and communication about future issues.

Project team members and organisations have enhanced knowledge of the economic, environmental and social limitations of vegetable producers. They have built confidence and understanding in vegetable production technologies and improved capacity to discuss and extend project findings. The project has built capacity among team members in project reporting and authoring. Australian and partner project staff worked together through the project to prepare 34 reports (see 10.2.3) and numerous presentations. Five abtsracts were collaboratively written, presented at the international TropAg2019 conference in Brisbane and published in the open source Proceedings journal (see 10.2.2). Four papers have been submitted to Lao journals and five papers are in preparation for publication in international journals (see 10.2.1). Ms Xiong (NUoL, Lao PDR) applied in 2020 for a JAF PhD scholarship.

8.2.2 Individual practice change

Farmers: Irrigation scheduling practices were modified by at least 50 farming families in an organic farming village (Thaxang) that was not directly associated with the project other than receiving some training delivered by CADC, a project collaborator. The farmers tried watering once per day rather than twice and were happy with the change, citing reduced time, labour, electricity and water requirements (and no noticeable decrease in yield). Further training may be required to encourage farmers to further adjust the irrigation volume applied according to crop needs using extension materials developed by the project. The simple 'once per day' irrigation message presents some risk, as it is only a logical change to make if farmers were previously applying twice the volume the crop needed. Early baseline measurements show that applying twice the water needed is indeed common, but the solution is more nuanced than simply watering 'once per day', as correct application needs to take into account the stage of crop growth and the time of the season. *See Lao PDR Irrigation video* Thaxang-Organic Farmers.mp4.

In Cambodia, 49% (Kampot) and 61% (Siem Reap) of farmers indicated they were adopting the use of lime applications in vegetable soils (Figure 42). These levels indicated a seven fold increase in Kampot and a doubling of farmer numbers in Siem Reap since the start of the project. Although there was initial difficulty finding farmer participants to establish demonstration sites with altered irrigation practices, interest increased over time. Some farmers are also trialling new irrigation practices and are interested to apply the recommended fertiliser rates in vegetable crops. (See data section 7.5.5, Table 39, Table 40, Table 41).

8.2.3 Institutional and group practice change

Livelihoods analysis identified key factors which potentially could contribute to the adoption of soil and irrigation practices including education levels, availability of information, cost of input supplies, low profits and availability of cash. Research results were considered relevant to the project participants and the business activities of smallholders in terms of savings of inputs (labour and fertiliser costs) and potential enhancement of profits from application of lime, along with potential water savings; this was an aim of the participatory communication and engagement approach used. These initial livelihood and farming systems studies have helped government and project organisations to develop a deeper understanding about important farmers' issues regarding adoption and change, and to become more aware of the limitations and aspirations of vegetable producers.

The project supported training and resourcing of local extension staff in irrigation and nutrition of vegetable cropping soils. It also communicated with and identified stakeholders who are prepared to work with institutions and improve communication with institutions around problems in vegetable production. The contacts and connections developed as part of this project have created an informal network of supportive projects, companies and organisations who will continue to work together to aid scale-out of project findings and improve future extension strategies and vegetable production in both countries,

In response to COVID-19 social distancing requirements, all research partners adapted quickly by identifying new methods for extending research results and evaluating project impact without the need for face to face contact. This included development and publishing of videos about irrigation practices on social media and scheduling and posting of farmer notes online. With increasing use of mobile phones and reasonable data coverage, the concept of farmers seeking information from online environments may have longer term implications in guiding in-country extension operators to increase their focus on information provision online.

8.2.4 Policy implications

The completion of projects can mean that project findings are at risk from further scale-out and extension. A commitment by participating organisations to continue to carry out extension and education with communities about this and other project findings will contribute to a focus on innovation and learning within rural communities.

Input supply shops are a key source of products and could also provide information and contacts for farmer clients. It is suggested that Government extension include input supply shops and Non-government Organisations and other projects as key clients for their extension activities. This could be through provision of information as farmer notes or web links and invitations to field days and workshops. Also if these organisations could be encouraged to play a role as a source of agricultural information and contact details which can be provided to farmers when needed. This will help educate a larger number of vegetable businesses which together could form a network focussed on improving production and profits for all.

As outlined in Section 7.1. a government role in testing and registering agricultural products could contribute to ensuring quality and trueness of products.

With increasing use of mobile phones and connectivity it is now opportune for extension projects to increase the availability of agricultural technical information online – through existing websites and creating new websites and partnering with commercial organisations for the promotion and publication of this information. This includes the use of videos and case studies and posting and promoting links to these in farmer Facebook groups and Youtube.

8.3 Community impacts – now and in 5 years

During the project, field days, farmer notes distributed to farmers and online and videos disseminated by social media helped local farmers to understand the benefits and consider applying lime in their vegetable-producing soils. Through participation in this project farmers, input suppliers, NGOs and commercial organisations have been part of the informal network learning to improve their knowledge of vegetable production practices. This project has resourced this informal network of people and organisations and provided information and contacts which will continue to support members in an ongoing sense. Over the next 5 years, the PDA in Cambodia will continue to provide extension to other farmer groups and within networks of suppliers, NGOs and commercial operators. In Lao PDR, farmers expressed a continued need for information on soil fertility and irrigation through radio and television and government extension officers are willing to provide extension to farmers and inputs shop owners.

Early socio-cultural research identified different constraints and impact pathways among men, women, and local groups including education, availability of resources, information, gender roles, time and labour. These differences were accommodated in the extension program by targeting and presenting key information verbally and visually in villages to farmers and providing technical information in printed and online video form, and enhancing farmer support networks. Continued consideration and use of these varied approaches in future extension will help build future capacities and outcomes.

Community impacts should continue well beyond the life of the project (e.g. 10 years), as findings are scaled out (more participants) and scaled up (use of more resources) and incorporated into agricultural practices for improved economic outcomes of individual enterprises and, collectively for the villages. Possible negative impacts were identified during the development and roll-out of extension messaging. For example, messages around 'irrigating once per day' that fail to also give guidance as to how much water should be applied (and how to calculate that amount), could lead to under-watering and mistrust in the research. Similarly, applying too much lime on soils that do not need it could have negative impacts on yield. Extension messages therefore need to be communicated accurately to and by research partners and extension staff, and with a full understanding of the circumstances in which they apply. Planning is needed to ensure extension activities continue to occur and ensure the project's findings are delivered to smallholders in areas beyond the current focus areas.

8.3.1 Economic impacts

Anecdotal cost:benefit analysis suggested that adopting the project's lime recommendations could increase profits per crop for smallholder vegetable farmers by almost 50% in Siem Reap and 13% in Kampot on average in Cambodia. Similarly for recommended NPK rates, the project in Cambodia identified 34% improvements in profits (Siem Reap) and 5% improvements in profits (Kampot) on average from applying recommended NPK rates in vegetables. In Paksong, Lao PDR, investing in fertiliser at optimum rates of N, P and K returned a profit 13 times higher than for optimum rates of N alone. Over 64% of participant farmers in Siem Reap province and 47% in Kampot Province believed that applying lime to vegetable producing soils resulted in a higher yield and approximately 90% of Cambodian participating farmers indicated they would like to trial lime in their crops. If economic returns are achieved as indicated in crops, then farmers will be able to afford to pay suppliers following harvest for the additional lime costs. Fertiliser nitrogen use by vegetable growers could reduce by up to 37 t p.a. in Cambodia.

Applying only the amount of water required by the crop leads to economic benefits by increasing crop production, savings on energy, pumping, fertigation (irrigation incorporating nutrients) and water costs. By adopting the irrigation guidelines, farmers can generally reduce the time they spend watering their crops by more than 60% and this allows them to use that time doing other tasks and/or reduce labour costs. Water use, and electricity costs for water pumping, can be commensurately reduced. There are potentially significant advantages to be gained through extension of the growing season, particularly in regions where stored water supplies are insufficient to support irrigated crop production for the duration of the dry season. On superficial analysis, the use of predicted ET_c irrigation scheduling practices could conceivably allow the area of vegetables grown to double (if land was available) without placing any greater pressure on water resources.

The project proposed to directly engage with approximately 30 – 35 participating households in at least two villages in each of two provinces in Lao PDR and Cambodia, a total of 200 farmers (the Project Villages). This projection was exceeded with 240 households in the Livelihoods analysis and almost 850 farmer attendees at field days over the project's duration. It was anticipated that the project would indirectly influence another six scale-out villages (400 farmers). In Cambodia alone, eight additional villages (beyond the project's participating villages) received information and explanation about lime and NPK recommended practices. It is estimated that a further 140 farmers from more scale-out villages will receive project technical information through extension after the project's completion, and other projects. Interactions with stakeholders (estimated at 30 stakeholders in Cambodia and 50 in Lao PDR) hopefully will further extend this figure. Future publishing of online video and technical information may extend scale out figures.

8.3.2 Social impacts

The project has provided an avenue (through village discussions and in the Livelihood and Farming Systems and Input Supply studies) for farmers and suppliers to identify their concerns, needs and expectations in relation to vegetable production and input supply chains. It has contributed to building knowledge and a technical focus among female farmers and contributed to enhancing Government and project understandings about their vegetable farming communities, their needs and ability to make change.

Dry season vegetable production by smallholders is limited by availability of male labourers when these family members are engaged in coffee or rice production activities well into the dry season, when vegetable production is at its peak. The project identified that irrigating in line with crop demand can reduce labour demands for this task. The scale of increase in income through more profitable fertiliser and lime practices achieved in project economic calculations (34-50% increase in profits in Siem Reap and 3 – 13% increase in profits in Kampot, along with 60% irrigation time savings through irrigation strategies) could ultimately improve the livelihoods and lives of all smallholder vegetable farmers. The use of fertiliser and irrigation inputs in agriculture are key indicators of the ‘non-poor’ rural community members in Cambodia (Engvall et al., 2004). COVID restrictions in 2020 are estimated to slow growth in the Cambodian economy. Two thirds of the 1.6 million rural households in Cambodia are faced with food shortages (IFAD, 2019). A large percentage of those classed as marginally out of poverty are further at risk with an economic slowing (World Bank, 2020). Maximising the efficiency of fertiliser and irrigation inputs will enable rural community members to maximise value from their available land to produce vegetables, aiding to maintain living standards, access sufficient food, and remain above the poverty line. Farming systems that utilise manual labour more efficiently may enable farmers to expand vegetable cropping areas to ensure an economy of scale that provides sufficient cash-flow (e.g. per crop) to incentivise and support them to invest in inputs.

The project has identified key local contacts (from PDA, from other projects or from NGOs and companies) who potentially can support vegetable farmers in the case of future problems and provide new information or source technical advice. This level of support enhances the human capital available to villagers for enhancing the profitability and sustainability of their farming systems. It is hoped that project field days and discussions in villages have created a social confidence to share experiences and learnings to facilitate future innovation in vegetable production.

8.3.3 Environmental impacts

Better irrigation scheduling reduced the amount of water used by over 60%, suggesting that this water was not needed by the crop and was previously being lost by leaching, soil evaporation and/or runoff. The water saving preserves a precious resource, allows a larger area (rarely available) to be irrigated and reduces the water loss to the off-farm environment. Alone, and in combination with better balanced and reduced and/or better matched fertiliser rates (directly by change in practice and indirectly by applying lime and increasing availability of soil nutrients), better irrigation practices reduce the potential for nutrient leaching and runoff into groundwater, rivers lakes and streams and thus reduces the eutrophication and water quality pressure on the off-farm environment. Waterlogging and the potential for denitrification and associated greenhouse gas emission will also be reduced by adoption of the project findings.

Through facilitated discussions it was identified that farmers were concerned about the health of themselves and the environment, the sustainability of farming systems and the need for efficient irrigation practices, thus highlighting to government the importance of these issues to communities. Adoption by participating households of new lime, fertiliser and irrigation strategies will contribute to the sustainability of vegetable production through preserving the quality of vegetable-producing soils and saving water resources. The concept of efficiencies in fertiliser and water inputs developed and promoted in this project can potentially be a key focus by governments and farming communities to contribute to prolonged sustainability of vegetable production.

8.4 Communication and dissemination activities

Internal communication was maintained via face to face, online team meetings, email and social media channels. Three meetings with representatives from the whole project team were held (Inception, Mid-term and online Final Review) and separate Annual Meetings were held in Lao PDR and Cambodia in the intervening years of 2016, 2017 and 2019. Seventeen trips were made to Cambodia and/or Lao PDR by Australian partners between September 2015 and February 2020. The Final Review meeting was hosted online in May 2020 due to travel and meeting restrictions caused by the COVID-19 global pandemic. The online review used an online Storyboard document, one on one phone call discussions between the reviewers and project participants, and online group meetings.

Joint meetings of team members from projects SCMN 2014/088 and ASEM 2012/081 were held on 8 February 2016 in Melbourne, Australia, in December 2018 in Kep, Cambodia and in November 2019 in Brisbane, Australia. Co-operative research occurred as co-location of an irrigation study in Siem Reap, joint delivery of soil and irrigation training to partners and farmers, joint field inspections of pest and disease pressure, and knowledge exchange on value chains.

The project has consulted with and built a network of agribusinesses, Government and NGOs interested in understanding lime and irrigation management in vegetables and some of which are able to provide extension to other farmer groups as a potential scale-out. Letters to Cambodian Government in relation to input supply chain recommendations hopefully will contribute to development of future policies supporting safe vegetable production.

Distribution of project reports, letters to stakeholders including extension agencies, input suppliers, other projects and NGOs and distribution and explanation of technical information to farmers and stakeholders will ensure awareness of project findings.

Extension materials overview: Farmer notes outlining improved techniques for management of NPK fertiliser, lime and irrigation have been produced for both Lao PDR and Cambodia. This information was provided to farmers across 11 villages and stakeholders in Cambodia and published online. Lao material will also be distributed. Written train the trainer material related to irrigation management and covering the use the Daily Application tables and the nomograph has been produced in English, Lao and Khmer. An English language video demonstrating these techniques has been produced. Lao videos with lime, fertiliser and irrigation extension messages have been produced and will be distributed. Khmer videos have not been produced due to COVID and time restrictions and skill limitations.

Numerous dissemination events and avenues have shared project findings. These include workshops, small group training, field days, and social media links to extension materials.

Australian and partner project staff worked together to prepare 38 technical reports. Five abstracts were presented at the TropAg2019 conference in Brisbane which was attended by over 800 delegates spanning 43 countries, and the abstracts were subsequently published as open source. A project poster was presented at a Vegetable Forum in Vientiane, Lao PDR in November 2019. Four journal articles have been submitted to Lao journals and five publications are in preparation for submission to international journals. These publications have enabled project data, strategies and achievements to be shared with the scientific community.

A project website was set up early in the project but had limited activity so a new showcase website was developed for the project as part of the online final review (https://utas.shorthandstories.com/2020_Cambodia_ACIAR). The website was used to share narrated final review presentations, comments and responses amongst the project team during the review process. It is now a non-interactive repository of the presentations, project technical reports and training and extension materials in Khmer, Lao and English.

9 Conclusions and recommendations

9.1 Conclusions

The project has identified that application of lime, recommended rates of NPK and new irrigation strategies can reduce costs and/or increase yields, and hence profit. These strategies provide opportunities for vegetable farmers to enhance production, protect soils and to improve income.

In Cambodia, there is widespread interest in applying lime (90-95% of farmers surveyed in Cambodia). Farmers believe applying lime results in higher yield (47% Kampot farmers, 64% Siem Reap farmers), and less disease (28% Kampot farmers, 2% Siem Reap farmers). Ten percent of farmers in Kampot (and 21% of farmers in Siem Reap) will decide on testing lime after more observations. Since the project, farmers adopting lime application on vegetable soils has doubled in Siem Reap and increased 7-fold in Kampot.

Constraints to adoption include access to lime and the financial outlay to purchase. There is good interest in applying new irrigation strategies with almost 40-72% of farmers in Cambodia surveyed willing to try new practices. Literacy levels may also be a constraint to understanding new soil and irrigation strategies, especially for those who are part of project scale-out who have not attended field days or explanatory discussions.

The project has provided useful information to meet farmer's needs about vegetable production and the sustainability of cropping soils, in particular improving soil nutrient management and conserving water. The project has improved awareness, knowledge and understanding among farmers in strategies to improve soil and irrigation management. Lime and new irrigation strategies will now be part of vegetable production systems in Kampot and Siem Reap.

The project team concluded that if the lime, fertiliser and irrigation research findings were adopted on a wide scale, then dry season vegetable production in Lao PDR and Cambodia could at least double (largely impact of lime) with half the water use and no extra land in production.

9.2 Recommendations

To increase the impact of the project on farmer livelihoods:

- There is a need for further exposure and training related to the use of the nomograph for irrigation scheduling, particularly of provincial agricultural extension staff in Cambodia, and HRC/NUoL and agricultural extension staff in Lao PDR.
- Irrigation scheduling information needs to be scaled up and out with capacity building for trainers, and the development of daily application data for a wider geographic range of provinces that represent major vegetable producing areas in both countries. Making the FAO ET_c process app-based would make it more easily accessible for those with smart phones, although it is likely that many growers may need other methods, such as the daily application tables and nomograph.
- A contacts database be maintained of stakeholders involved in supporting vegetable production including input suppliers, company representatives, NGOs and other projects; and for extension staff to liaise with other vegetable research e.g. World Vegetable Centre to access and share information on new technologies and practices.

The project has revealed new research questions. Future research for development projects should focus on the following research areas:

1. Consideration be given to development of projects in integrated pest management under the appropriate ACIAR program, as weeds, pests and diseases were identified as a major production limitation.
2. Can permanent beds in vegetable production be adopted by smallholder vegetable farmers to improve their yields and livelihoods? Can this improve the role of women in the vegetable value chain? The work of CE-SAIN on permanent beds at Siem Reap shows an obvious direction for improvement of soil structure in vegetable growing soils. The challenge is to transition that permanent bed research work into an adoptable option for on-farm use, and this transition could be a focus of a future ACIAR project.
3. What is the impact on vegetable yield of improved composting techniques and compost quality? Future work in this area could include testing of OM materials, understanding the relevance of C:N ratios in compost management in smallholder vegetable farming, training people in correct composting techniques and compiling generic information about C:N ratios and implications for compost application rates.
4. What is the yield potential of vegetable crops in south-east Asia? With proper management and similar production systems, similar yields could be achieved as in Europe or the US, but nitrogen fertiliser dynamics and efficiency are somewhat different. Establish sound nutrient requirements for localised conditions and newly introduced vegetables.
5. What is the impact of climate change on smallholder vegetable farming? For example, the ‘sandy soils’ around the Mekong plain of Cambodia are under-developed as the water table depth changes with time in a year. This issue is important for the sustainability of vegetable growing. Loss of nutrients and other inputs to vegetable production through over-irrigation and ground water transfer is also a potential source of contamination downstream water bodies.
6. Can better seedling management improve vegetable yields and livelihoods for smallholder farmers? For example, it is suspected that plant growth is interrupted by transplant shock, and extreme over-watering appears to be the local solution to overcoming this. A change to cell transplants may shorten the growing cycle, require less water, potentially remove the need for transplant shading (and the associated capital and labour costs), allow more crops to be grown per season and provide benefits for pest and disease management. Some growers already report that using cell transplants for particular plantings results in more robust seedlings, but the practice is not widespread due to the perceived costs of seedling production (labour and infrastructure), although there are many potential benefits that could offset that cost. There is also the potential for alternative approaches to the production of cell transplants that do not require the use (and expense) of plastic cell trays such as those widely used in Western production systems.
7. How can nation-wide initiatives incorporating public and private operators be established and operate to collate, share and integrate findings from vegetable research (from SE Asia) in order to improve the sustainability, profitability and adaptability of vegetable production?
8. How can a self-help, community-led focus be developed for local village farmers to create and drive future initiatives in climate change adaptation and vegetable production innovation?
9. Value chain analysis and interventions to identify and maximise education and adoption of handling, packing and transport initiatives to support scale out of ASEM 2012/081 and other research findings within Siem Reap Province.

To enhance the success of future projects of a similar nature, ACIAR and its research providers should:

- ensure sufficient resource is allocated to support and train partners for implementation of rigorous research methods early in the project and for dissemination of technical information,
- undertake early field trials on research stations rather than on farms due to the high risk nature of field trials and to build confidence in the project team and data, and
- provide translation services during key meetings and discussions, and for report production.

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10.2 Publications produced by the project

10.2.1 Journals

Xiong, M., Khammouane, T., Bonney, L. and Palaniappan, P. (2020) Organic Manure Supply and Standards Constraints in Paksong District of Champasak Province in Southern Laos. National Agriculture and Forestry Research Institute Journal. (Submitted May 2020)(Lao)

Abstract: This survey is aimed to determine the animal manure chain back to its source to identify the geographic movement and constraints in the animal manure input supply chain to the horticultural industry in the Paksong District of Champasak Province in Southern Laos. This study was conducted in June 2019. The Laos Project Team conducted a range of small group and individual interviews in Paksong District of Champasak Province and in Saravan District of Saravan Province (the neighboring province of Champasak). The results of the survey identified that the movement of cattle and chicken manure is largely within and between neighboring provinces and does not cross-national boundaries (with Vietnam). It concluded that demand is growing rapidly with Foreign Direct Investment in horticulture in the Paksong District and it is a relatively simple supply chain with low margins taken by traders. However, the investigation did identify that a number of related issues were possibly constraining the improvement of the horticultural industries in the Project's focal provinces. An example was the lack of a price incentive for 'organic' produce in Laos may be hindering the more widespread adoption of the Organic Standard as part of the Clean Agriculture Development Action Plan.

Xiong, M., Southammavong, F., Bonney, L., and Palaniappan, P. (2020) Methodology for Value Chain and Livelihoods Analysis. Journal of Agricultural Science, Technology and Development, JASTD. (Submitted by May 2020)(Lao)

Abstract: Quantitative and qualitative research methods were employed to conduct research activities for objectives 1 and 2 of the research project "Integrating soil and water management in vegetable production in Lao PDR and Cambodia project, SMCN/2014/088". Quantitative research includes systematic investigation of phenomena by gathering quantifiable data and performing statistical, mathematical, or computational techniques. Qualitative inquiry deals with how social experience is created and given meaning, and quantitative inquiry deals with measurement and analysis of casual relationships. This paper describes the methods used to understand participants' social experience with respect to input supply chains and livelihood. The quantitative method employed in this study was a household survey. Quantitative research methods involve a larger sample and do not require a relatively long time for data collection. Some limitations are that quantitative research methods take snapshots of a phenomenon and do not allow for in-depth understanding. The qualitative methods employed in this study included Semi-Structured Interview (SSI), Focus Group Discussion (FGD) and Participatory Resource Mapping. Qualitative research methods allow deeper insights into respondents' perceptions, feelings, and understanding. Some weaknesses are, for instance, smaller sample sizes and time consuming conduct and analysis (Silverman, 2016). Using both quantitative and qualitative methods would allow researchers to measure and understand the meaning provided through responses from participants.

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Xiong, M., Southammavong, F., Sisouvanh P., Somphou, I., Khammouane, T., Bonney, L. and Palaniappan, G. (2020) Inputs Supply Chain Analysis for Vegetable production in Vientiane Capital and Champasak Province, Lao PDR. Journal of Agricultural Science, Technology and Development, JASTD. (Submitted April 2020)(Lao)

Abstract: An Inputs Supply Chain Analysis was conducted during 2017-2018, with the purpose of analyzing input supply chains and identifying opportunities to improve their functioning and performance to deliver inputs to farmers in a timely and efficient manner. A survey took place in 3 villages of two districts in Vientiane capital and 2 villages of Paksong District, in Champasak Province, Laos. The overall approach adopted was Participatory Action Research using mixed qualitative and quantitative methods to collect input supply chain data. An emphasis on structured interviews and quantitative survey was necessitated due to inexperience with semi-structured qualitative techniques. A structured economic survey was conducted with 105 respondents almost equally divided between Vientiane and Champasak. The respondents included farmers, small shop owners, inputs companies, input importers and input manufacturers. The result of the survey shows that, the main crops in the study areas were Lettuce, Mint, Thorny Coriander, Cabbage, Maize, and Lime. The majority of the vegetable inputs including fertilizers, seeds, pesticides and farm tools were mainly imported from Thailand, secondly from Vietnam, while lime and animal manure locally sourced. This survey concluded that there is no manufacturer of inputs in Laos, except white lime. Laos has reserves of rock phosphate and the Laos Government should consider ways of obtaining foreign direct investment to enable the exploitation of those reserves. The upstream input supply chain is quite opaque and that appears to be due to both business confidentiality and the main suppliers being in external countries.

Xiong, M.; Southammavong, F.; Sisouvanh P.; Somphou, I, and Palaniappan, P. (2020) Livelihoods analysis of vegetable producing household members and socio-economic and socio-cultural analysis related to adoption in Vientiane and Champasak. National University of Laos Journal (Submitted May 2020)(Lao)

Abstract: Agriculture is the primary source of income for poor rural people. Sustainable livelihood analysis allows researchers to understand how poor people construct their lives by taking advantage of different opportunities and resources. The conceptual framework was used to analyse the causes of poverty and peoples' access to resources (tangible and intangible) for their livelihoods. The resources include five capitals: natural, physical, financial, human and social. The household survey was conducted in selected intervention site villages: Pakxapkao (Xaithany district, Vientiane Capital), Huaha (Hadxaifong district, Vientiane Capital), Thongset (Paksong district, Champasak province) and Katouad (Paksong district, Champasak province). The survey was implemented during 2017 and 2018, with a total of 114 respondents who were purposively selected from the sites to complete the household surveys. Purposive sampling was conducted deliberately to gain representative samples through judgement combined with selection criteria. Data analysis using standard descriptive statistics is the focus of this baseline analysis.

Results presented here are the overall baseline survey results which included household demographics, physical capital, financial capital, human capital, environmental capital, and social capital. In the Sustainable Livelihood Framework, five livelihood or capital assets lie at the centre of sustainability. This survey concludes that these assets represent all spheres of materials, services, and opportunities available to people to adopt innovations to meet their basic needs, and in mitigating or adapting to disruptive change.

In Preparation

Bonney, L. et al. (In Preparation) Constraints to adoption of 'organic' and 'GAP' standards by smallholder vegetable farmers in Lao PDR.

Eberhard, J., et al. (In Preparation) Balanced NPK fertiliser application improves yield and income of smallholder farms in Lao PDR and Cambodia.

Jones, S., et al. (In Preparation) Importance of managing soil acidity for smallholder vegetable farming in Lao PDR and Cambodia.

McPhee, J., et al. (In Preparation) Irrigation scheduling for small-holder vegetable farmers in Lao PDR and Cambodia.

Palaniappan, G. et al. (In Preparation) Livelihoods analysis reveals opportunities to influence practice change in smallholder vegetable farmers in Lao PDR and Cambodia.

Starasts, A. et al. (In Preparation) Input supply chain constraints and opportunities for smallholder vegetable farming in Lao PDR and Cambodia.

10.2.2 Conferences

Birch, CJ and Bonney, LB and Ives, SW and McPhee, J and Bounneuang, D and Seng, V and Sokun, B and Sacklokham, S, "Whole of System and Value Chain Analyses reveal research needs in horticulture in Laos and Cambodia", Proceedings of the Tropical Agriculture Conference, 16-18 November 2015, Brisbane, Australia, pp. 1-2. (2015) [Conference Extract Filename *Birch et al 2015 TropAg.doc* and Poster Filename *Birch et al 2015 TropAg Poster.pdf*)

Abstract: Whole of system and rapid value chain analyses were used to assess biophysical and input constraints to vegetable and fruit production in the Mekong River Valley, Lao PDR and Cambodia. In both countries, the assessment involved visits to vegetable and fruit producing areas, field inspections, interviews with smallholders, research and development institutions and support businesses, collection of field data and review of literature pertaining to resource constraints. Specific themes were distilled from the gathered information, and, whilst soil and water management was the focus, the approach identified other constraints and opportunities for system improvement to enhance production and income at the farm level and along the input value chains. These included pest management, and crop and cultivar phenology and adaptation. It became clear that the capacity for introduction of high technology input systems was constrained by finance, farm scale, regulations and socio-cultural expectations. Significantly, it revealed that substantial gains could be achieved in the short to medium term by applying low-input sustainable solutions to existing production systems. This would involve some purchased inputs including soil ameliorants, 'soft' chemicals, improved cultivars and small-scale mechanization. However, the analysis also revealed that high-input systems should be included in research projects to assess their productive potential in the Lao and Cambodian environments. Training of support staff and smallholders was identified as a key to fostering and enhancing adoption of improved production technologies, and that these aspects needed to be underpinned by socio-cultural research for the development of effective extension strategies.

Hin, S.; Touch, V.; Lim, V.; Eberhard, J.; Melland, A.R.; McPhee, J.; Jones, S.; Ives, S.; Seng, V. (2019) Lime and Fertiliser Applications Increase Yield of Leafy Vegetable Crops in Cambodia. Proceedings 2019, 36, 179. (Viewed 75 times since 9/5/2020 presented as a poster at TropAg2019, November 2019, Brisbane, Australia, attended by 823 delegates)

Abstract: Growing vegetables after rice harvest allows Cambodian farmers to use land that would otherwise be unproductive between rice crops. Producing vegetables on these soils is limited by low soil pH, low cation exchange capacity and limited nutrient retention capacity. Soil pH in the top 20 cm is generally low (pH 5.5 H_2O) and may limit the availability of nutrients. Farm-based trials in Siem Reap and Kampot provinces assessed the effect of lime and fertiliser on leafy vegetable crop growth and yield. At lime-only sites, lime was applied at rates of 0.5, 1.0 and 2.0 tonnes per hectare (t/ha) in conjunction with farmer practice fertiliser rates. For sites with lime and fertiliser treatments, combinations of farmer practice and optimal fertiliser rates, no lime and 2.0 t/ha of lime were applied. Two consecutive crops were planted at one site to examine the residual effect of lime on soil pH and crop yield. At lime-only sites, all crops responded to lime application with yield increases of up to 100%. For sites that assessed combinations of lime and fertiliser, the treatment of lime and optimum fertiliser rates showed the highest yield increase (92%). Application of 2.0 t/ha lime increased soil pH by approximately 1.0 unit. This effect was still evident after a second crop of Bok Choy. For the 0.5 t/ha lime treatment, an initial soil pH increase of 0.4 units had reduced to 0.2 units after the second crop. The first crop yield was higher than the second crop yield. Long-term field trials are needed to examine residual lime effects.

McPhee, J.; Jones, S.; Ives, S.; Melland, A.; Eberhard, J.; Sisouvanh, P.; Somphou, I.; Boupha, B.D.; Mounsena, P. (2019) Evaluation of the Effect of Lime and Irrigation on Lettuce Yield in Laos. Proceedings 2019, 36, 185. https://doi.org/10.3390/proceedings2019036185 (Viewed 126 times since 9/5/2020, presented as a poster at TropAg2019, November 2019, Brisbane, Australia, attended by 823 delegates)

Abstract: Diversification of food sources and agricultural production systems has potential to enhance domestic supplies and provide export market opportunities for Laos. Major constraints to agricultural productivity are related to soil management and include inefficient irrigation, poor soil structural stability, low pH and nutrient availability. An experiment at the National University of Laos (NUOL) in Vientiane assessed the effect of lime and irrigation scheduling on growth and yield of lettuce. The soil was a sandy clay loam with pH 4.89 (H2O) in the top 15 cm. Lime (CaCO3) was applied at rates of 2 and 4 tonnes per hectare (t/ha). Irrigation scheduling was based on calculated evapotranspiration (ET_c) with frequencies of either twice daily, once daily or alternate days. Urea, chicken manure and rice husks were added to soil in all trial plots. The experimental design was split-plot with two treatments (lime and irrigation scheduling) and four replications. The combination of 4 t/ha lime and irrigation every second day had the highest yield (mean > 2 kg/m2). The combined treatment of irrigation once a day and no added lime showed significantly higher leaf number ($p = 0.01$) and plant height ($p < 0.001$) compared to the other treatment combinations. However, increased biomass of individual plants did not translate into increased marketable yield per square metre. The application of lime raised the pH of soil but the effect on plant growth and yield was not conclusive. Separation of the two treatments into single factor trials is needed to elucidate the effects of individual treatments in future trials.

Sisouvanh, P.; McPhee, J.; Jones, S.; Ives, S.; Melland, A.R.; Eberhard, J.; Vilayphone, T.; Mounsena, P.; Douang Boupha, B. (2019) Evaluation of the Effect of Organic Fertilisers on Lettuce Yield in Lao People’s Democratic Republic (PDR). Proceedings 2019, 36, 183. https://doi.org/10.3390/proceedings2019036183 (Viewed 82 times since 9/5/2020, presented as a poster at TropAg2019, November 2019, Brisbane, Australia, attended by 823 delegates)

Abstract: Production of leafy vegetables, such as lettuce, in Lao People’s Democratic Republic (PDR) is limited by low nutrient soils. Organic fertilisers or composts made from agricultural residues may provide Lao PDR farmers with economical and environmentally sustainable alternatives to chemical fertilisers. Research is needed to increase awareness and knowledge of organic fertilisers suited to vegetable production in Lao PDR. An experiment at the Horticultural Research Centre (HRC) in Vientiane assessed the effect of four organic fertilisers on growth and yield of lettuce. Two commercially available fertilisers (fermented manure compost and an organic fertiliser) were compared with a mixture of cow manure plus rice husks, and a fourth compost made from vegetable leaves, straw and cow manure at the HRC. The experimental design was a randomised block with four replicates for each fertiliser treatment. Lettuce was grown in raised beds with 10 tonnes per hectare (t/ha) fertiliser applied before seedlings were transplanted. The fermented manure compost treatment had the highest yield (1.95 kg/m2) and was significantly higher than the other three treatments ($p < 0.001$). Growth rates were also highest for the fermented manure compost at all measured growth intervals (14, 28 and 45 days after transplanting). Rapid nutrient release from fertiliser is important for short-term crops. The higher growth rates and yields found for the fermented manure compost indicate that nutrients were released sooner and were more readily available compared to the other treatments. Mature compost releases nutrients more rapidly than compost that contains partially decomposed rice husks, vegetable leaves and straw.

Starasts, A.; Ratana, T.; Putheavy, Y.; Kay, R. (2019) Investigating Capacities to Change Soil and Irrigation Practices in Vegetable Production in Two Provinces in Cambodia. Proceedings 2019, 36, 210 https://doi.org/10.3390/proceedings2019036210 (Viewed 105 times since 9/5/2020, presented as a poster at TropAg2019, November 2019, Brisbane, Australia, attended by 823 delegates)

Abstract: Improving vegetable production in Cambodia offers a pathway to grow domestic consumption and exports, and improve nutrition, profits, and livelihoods. Interviews with 120 growers and 5 focus group discussions within 5 villages investigated growers' capacity to change soil and irrigation management in their Chinese cabbage, Petsai, Cucumber, Cauliflower, Lettuce and other vegetable crops. Low or no profitability (34% participants), insect pests (59%) and dry periods (18%) were growers' major limitations, with small farm size (0.08 ha) and limited schooling (21–36% had no schooling) contributing to the scenario. High cost of inputs is a limitation to making farming system changes, with most growers using their own funds and less than 10% borrowing funds to pay for crop inputs. Communication and planning for vegetable growing occurred almost exclusively within families (93%), with 7.5% of participants discussing with other farmers. Lack of time (43%) and knowledge about farmer group activities (30%) limited ongoing group learning opportunities. Although very traditional, 28% of participants had tried new practices; 42% of participants indicated they will try new practices after exposure to a soil and irrigation research trial. The participants were keen learners, and after exposure to the research, 58% believed that liming improves yields and 18% prefer to evaluate this on their farms. Information sources about vegetable growing are limited, and growers had complex information needs. Facilitating and mentoring ongoing local support and technical information networks, and enhancing capacity and communication are seen as key strategies for empowering long term ability to change.

Xiong, M., Bonney, L., Southammavong, F. and Khammouane, T. (2019) 'Integrating soil and water management in vegetable production in Lao PDR and Cambodia: input supply chain case study in Lao PDR', poster presented to NAFRI Vegetable Forum, Vientiane.

Xiong, M.; Palaniappan, G.; Bonney, L. (2019) Do GAP Practices Improve Market Access for Vegetable Farmers? A Case Study from Vientiane Capital, Laos. Proceedings 2019, 36, 78. https://doi.org/10.3390/proceedings2019036078 (Viewed 90 since 9/5/20, presented as a poster at TropAg2019, November 2019, Brisbane, Australia, attended by 823 delegates)

Abstract: A case study on Good Agricultural Practices (GAP) of vegetable was conducted in 2018, with an objective to understand whether GAP practices improve market access for vegetable farmers in the Lao PDR. The case study was conducted in Nasala Village, Xaythany District, Vientiane capital, Lao PDR. The data was collected using 10 semi-structured interviews and one group discussion with Nasala farmers. The results were summarized based on the themes such as community characteristics, market access and farmers' perception about GAP. The Nasala community has 585 households, majority being farmers with 50% of them growing vegetables with an average farm size of 1.5 hectare. District Agriculture and Forestry Office (DAFO) introduced GAP practices as a pilot project to 28 farmers in Nasala in 2014 through farmer trainings. The DAFO pilot project enabled Nasala farmers to export Thorny Coriander to Japan during 2016–2017.

Nasala farmers sold 50 kg/day of Thorny Coriander for about one year at the price of 15000 kip/kg in comparison to 7000–10000 kip/kg at the local market. Farmers agreed that they were motivated by the market incentives and collectively sold the produce by alternating production for continuous supply. This export opportunity was withdrawn after the pilot period resulting in no incentives to practice GAP. Farmers agreed that GAP enabled them to produce better quality, healthier and safer vegetables. However, the barriers to GAP are lack of government policies, institutional support, inadequate incentives and complex certification process. To enable farmers to continue GAP practices appropriate supporting system must be developed.

10.2.3 Technical Reports

The following project technical reports (38) can be found on the website: https://utas.shorthandstories.com/2020_Cambodia_ACIAR

Birch, C., Bonney, L., Ives, S. and McPhee, J. (2014) Integrating resource management for fruit and vegetable production in Laos and Cambodia. SMCN/2014/015 ACIAR, SRA Final Report, Canberra, Australia

Bonney, L.B., Southammavong, F., Somphou, I., Mounsena, P., Xiong, M., Khammouane, T. (2020) ACIAR SMCN 2014 088 Objective 1 Lao PDR Final Report. University of Tasmania, Australia

Eberhard, J. (2020) Lime and Fertiliser Extension in Cambodia: Activities undertaken by a collaboration of staff from projects: SMCN 2014/088 and SMCN 2016/237 for the 'ACIAR Small R&D Activity No. SLAM 2018/127 X-projects and synthesis, Cambodia' Project, Final Report, April 2020

Hin, S., Touch, V., Lim, V., Seng, V (2017) Cambodia Annual Meeting Objective 3 & 4 Result Summary Siem Riep. Presentation for SMCN/2014/088 Annual Project Meeting, CARDI, Phnom Penh 10-11 August 2017

Hin, S., Touch, V. Lim, V. Seng, V., Eberhard, J and Mc Phee, J. (2018) ACIAR SMCN 2014 088 CARDI Demonstration Site Report July 2018, Technical Report, CARDI, USQ, UTAS.

Hin, S. and Touch, V. (2019) ACIAR SMCN 2014 088 CARDI Demonstration Site Report July 2019, Technical Report, CARDI.

Hin, S. Lim, V., Touch, V., Eberhard, J., McPhee, J., Hay, V., Touch, K., Prum, B. (2019) Objective 3&4 Demonstration trial report. Presentation. CARDI, USQ, UTAS, PDAFF

Kivoravong, K., Mousena, P., Bounneuang, D., McPhee, J., Eberhard, J. and Jones, S. (2018a) Lao PDR SMCN Comparison of different mineral fertiliser rates on yield of lettuce in Phonethong district, Champasak, Lao PDR, 2018-19, Demonstration Site Report, UTAS, USQ, NAFRI, HRC, PAFO

Kivoravong, K., Mousena, P., Bounneuang, D., McPhee, J., Eberhard, J. and Jones, S. (2018b) Lao PDR SMCN Effect of different NPK fertiliser ratios and rates on productivity of broccoli in Paksong district, Champasak, Lao PDR, 2018-19, Demonstration Site Report, UTAS, USQ, NAFRI, HRC, PAFO

McPhee, J., Eberhard, J. Vilavong, S., Mousena, P., and Bounneuang, D. (2017) Replicated experiments of the impact of nutrient treatments on crop growth and yield in Champasak Province, 2016-17, Lao PDR SMCN-2014-088 Champasak Province. Replicated Experiment Report. PAFO, UTAS, USQ, NAFRI, HRC.

Mounsena, P., Vilayphone, T., Bounneuang, D., Eberhard, J., McPhee, J., Jones, S. (2018) Using different fertilizers in growing the vegetable salads and spring onions in 2018 at the Research Center for Vegetables and Fruit (HRC). Technical Report. NAFRI HRC, UTAS, USQ.

Palaniappan, G., Xiong, M and Bonney, L. (2018) Identifying the drivers for adoption of innovation. Report, UQ, NUoL, UTas.

Palaniappan, G., Xiong, M., Southammavong, F., Sisouvanh, P. and Somphou, I. (2018) Baseline Livelihoods Analysis – Lao PDR. SMCN 2014 088 Technical Report, UQ, NUoL
Palaniappan, G. and Xiong, M. (2019) Value chain network analysis. Report. UQ, NUoL.
Palaniappan, G., Xiong, M. and Southammavong, F. (2019) Gender roles in vegetable production. Report, UQ, NUoL.
Sisouvanh, P., McPhee, J., and Eberhard, J. (2017) Lao PDR SMCN-2014-088 Xaithany District Experiment Report 2017: Replicated experiments of the impact of organic matter treatments on crop growth and yield in Xaithany District, Vientiane Capital Province, Lao PDR, 2016-17. UTAS, USQ, NUoL.
Sisouvanh, P. (2018) Effect of liming on lettuce yield. On Farm Demonstration, Pakxapkao, Vientiane Capital, Lao PDR, 2017-2018, NUoL.
Sisouvanh, P., Somphou, I., Eberhard, J., McPhee, J., Jones, S. (2018) Effect of liming and irrigation scheduling on lettuce yield. Replicated Experiment Report NUoL 2018, Vientiane, Lao PDR, 2017-2018, Technical Report, NUoL, USQ, UTAS
Sisouvanh, P., Eberhard, J., McPhee, J., Jones, S. (2019) Effect of liming and standardise NPK rates on lettuce yield. Demonstration Report Xaithany District 2019, Vientiane, Lao PDR, 2018-2019, Technical Report, NUoL, USQ, UTAS
Somphou, I., Sisouvanh, P., Liengnaboun, S., Visoutthivong, S. and Singkeodala, C. (2018) Replication Experiment of Water management in lettuce plantation in Lao PDR. Technical Report. NUoL
Somphou, I. (2019) Water management in lettuce plantation in Lao PDR. Technical Report
Starasts, A. (2019) Participatory Impact Pathways Analysis (PIPA). SMCN 2014 088 Integrating soil and water management in vegetable production in Lao PDR and Cambodia, March 2019. Technical Report. USQ
Starasts, A. and Tech, R. (2020) Extension for soil and water management in vegetable production in Kampot and Siem Reap Provinces SMCN 2014/088 Report. USQ, CARDI.
Starasts, A. and Tech, R. (2020) Livelihoods and farming systems - Cambodia. SMCN 2014 088, Technical Report. USQ, CARDI
Starasts, A., Tech, R., Yin, P. and Ratana, K. (2020) Vegetable Input Supply Chain Analysis-Cambodia. SMCN 2014 088, Technical Report. USQ, CARDI.
Tech, R. (2018a) Initial summary of interviews with input suppliers-Cambodia. ACIAR SMCN 2014/088, Technical Report. CARDI (confidential)
Tech, R. (2018b) Summary report farmer adaptation to new agricultural technology – Cambodia SMCN 2014 088, Technical Report. CARDI.
Touch, V., Hin, S., Lim, V., Seng, V (2017) Cambodia Annual Meeting Objective 3 & 4 Result Summary Kampot. Presentation for SMCN/2014/088 Annual Project Meeting, CARDI, Phnom Penh 10-11 August 2017
Uddin, J., McPhee, J. (2018) Progress on irrigation activities (Objective 4) for ACIAR project SMCN-2014-088. Technical Report. USQ, UTAS.
Vilavong, S., Mousena, P., Bounneuang, D, Eberhard, J., McPhee, J. and Jones, S. (2018a) Replicated experiments of the impact of nutrient and lime treatments on broccoli growth and yield in Champasak Province, Thongset, 2017-18, Lao PDR, Replicated Experiment Report, UTAS, USQ, NAFRI, HRC, PAFO (Lao, English)
Vilavong, S., Mousena, P., Bounneuang, D., Eberhard, J., McPhee, J. and Jones, S. (2018b) Replicated experiments of the impact of nutrient and lime treatments on broccoli growth and yield in Champasak Province, 35 km station 2017-18, Lao PDR, Replicated Experiment Report, UTAS, USQ, NAFRI, HRC, PAFO (Lao, English)
Vilavong, S., Mousena, P., Bounneuang, D., McPhee, J., Eberhard, J. and Jones, S. (2018c) Paksong (Lao-Viet station) irrigation experiment 2018, Lao PDR, Technical Report. PAFO, HRC, NAFRI, UTAS, USQ. (Lao, English)

Vilayphone, T., Mounsena, P., McPhee, J., and Eberhard, J. (2017) Lao PDR SMCN-2014-088 Hadxaifong District Experiment Report 2017: Replicated experiments of the impact of nutrient and organic matter treatments on crop growth and yield in Hadxaifong District, Vientiane Capital Province, Lao PDR. Technical Report. UTAS, USQ, NAFRI HRC.

Vilayphone, T. (2019) Lao PDR SMCN-2014-088 Hadxaifong District Experiment Report 2019. Technical Report. NAFRI HRC.

Xiong, M., Southammavong, F., Sisouvanh, P., Somphou, I. (2018) Soil characteristics and water for Lao farmers report. 1st November 2018, Pakxapkao Village, Xaythany District, Vientiane. Technical Report, NUoL

Xiong, M., Southammavong, F., Soysouvanh, P. and Chittarath, K. (2018) Pest and Disease Management Training, Technical Report, NUoL, PPC

Xiong, M., Southammavong, F. and Khammouane, T. (2019) Evaluation of Pest and Disease Management Training. Technical Report, NUoL, PPC

Xiong, M., Southammavong, F., Sisouvanh, P., Somphou, I., Douangboupha, B., Mounsena, P. and Vilayphone, T. (2020) Training for input suppliers and farmers and dissemination workshop Lao PDR. Report. NUoL, NAFRI HRC.

10.2.4 Extension and Training Material

The following project extension and training material can be found on the website: https://utas.shorthandstories.com/2020_Cambodia_ACIAR

Factsheets, Farmer Notes and Technical Notes

1. ACIAR SMCN 2014 088 (2018a) Applying lime in vegetables. Factsheet, Cambodia
2. ACIAR SMCN 2014 088 (2018b) Irrigating vegetables. Factsheet Cambodia
3. ACIAR SMCN 2014 088 (2019a) Daily application tables for irrigation of leafy vegetables in Cambodia. Technical Note (Khmer, English)
4. ACIAR SMCN 2014 088 (2019b) Daily application tables for irrigation of leafy vegetables in Lao PDR. Technical Note (Lao, English)
5. ACIAR SMCN 2014 088 (2020a) Vegetable growing-fertiliser, lime and irrigation Farmer Note Cambodia
6. ACIAR SMCN 2014 088 (2020b) Vegetable growing-fertiliser, lime and irrigation Farmer Note Lao PDR (Lao, English)
7. ACIAR SMCN 2014 088 (2020c) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Technical Note (Khmer, English)
8. ACIAR SMCN 2014 088 (2020d) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Technical Note (Lao, English)
9. ACIAR SMCN 2014 088 (2020i) Irrigating vegetables. Farmer Note Cambodia (English, Khmer)
10. ACIAR SMCN 2014 088 (2020j) Lime and fertilizer application for leafy vegetables on sandy acid soils (Prey Khmer and Prateah Lang soil groups). Farmer Note. CARDI (Khmer)
11. ACIAR SMCN 2014 088 (2020k) Irrigation management for short, medium and long leafy vegetable crops in Siem Reap and Kampot provinces. Farmer Note. CARDI (Khmer)

Videos and presentations

1. Sisouvanh, P. & Xiong, M. (2020) Irrigation, fertiliser and lime application videos
   - https://www.youtube.com/watch?v=2kfl4ycuXZw&t=260s (Lao)
   - https://www.youtube.com/watch?v=Agez_ubnyRw&t=31s (Lao)

- https://www.youtube.com/watch?v=bJvNV-7FPN4&t=60s (Lao)

2. ACIAR SMCN 2014 088 (2020e) Irrigation application for leafy vegetables in Cambodia using a nomograph and daily application tables. Training presentation (Khmer, English- narrated)
3. ACIAR SMCN 2014 088 (2020f) Irrigation application for leafy vegetables in Lao PDR using a nomograph and daily application tables. Training presentation (Lao, English - narrated)

Decision support tools

1. ACIAR SMCN 2014 088 (2018c) Distribution Uniformity-Infiltration Calculator - MS Excel Technical Aid for calculating irrigation distribution uniformity for hand-held hose, sprinklers and watering can irrigation systems, and soil infiltration rates.
2. ACIAR SMCN 2014 088 (2018d) ETc Irrigation Calculator. Siem Reap example. MS Excel Technical Aid for preparing district-based irrigation schedules for vegetable crops in Cambodia using FAO-equations for crop water demand.
3. ACIAR SMCN 2014 088 (2020g) Lime calculator. Android App. (Khmer, English, Lao) A simple smartphone app that calculates the appropriate application rate of lime depending on soil pH, soil texture, organic matter content and type of lime. Google Play "Lime Requirement Calculator" https://play.google.com/store/apps/details?id=com.lime_requirement_calc.app
4. ACIAR SMCN 2014 088 (2020h) Irrigation nomograph master. Technical Note (English-Khmer, English-Lao)

10.2.5 Travel Reports

Seventeen trips to Cambodia and/or Lao PDR were conducted by Australian partners between September 2015 and February 2020 as listed by the trip reports below. One trip by Cambodian and Lao PDR partners to Australia occurred in November 2019. Trip reports are available on request.

Birch, C. (2015) SMCN 2014 088 Trip Report #1 Sep 2015 Inception Meeting.
Bonney, L. (2019) SMCN 2014 088 Trip Report #15 June 2019 Lao PDR LB
Bonney, L. and Palaniappan, G. (2016) SMCN 2014 088 Trip Report #3 Nov 2016
Bonney, L., Eberhard, J., Jones, S., and Palaniappan, G. (2017) SMCN 2014 088 Trip Report #8 Oct 2017 AGM Laos
Eberhard, J. and McPhee, J. (2018) SMCN 2014 088 Trip Report #12 Sep2018 JE JM
Eberhard, J. and Palaniappan, G. (2019) SMCN 2014 088 Trip Report #16 Oct 2019 Cambodia - Lao PDR JE GP
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11 Appendixes

11.1 Appendix 1. Village and field site selection criteria

No.	Priority	Criteria	Scoring scales	Site 1	Site 2
		Village criteria			
1	H	Support by Local Government	moderate (3) good (6) | support very good (9)	6	9
2	H	Irrigation water availability	moderate (3) good (6) | availability very good (9)	9	9
3	H	Soil exhibits constraints relevant to focus of project	one (3) some (6) | constraints many (9)	9	9
4	H	Village farmers generally interested in new ideas related to soil management/irrigation	low (3) moderate (6) | interest good (9)	9	9
5	M	Irrigation water quality	moderate (2) good (4) | quality very good (6)	4	4
6	M	Diversity of ethnic groups	low (2) medium (4) | diversity high (6)	6 (Lao Lum, Lao Sum)	6 (Lao Lum, Lao Sum)
7	M (H for Siem Reap)	Near other project sites where appropriate	very far (2) far (4) close (6)	6	4
8	M	Village farmers are able to implement practice change i.e. economic and labour resources	low (2) medium (4) | resources high (6)	6	4
9	L	Range of production systems in village (high/low input)	small (1) moderate (2) | range large (3)	3	3 (org, GAP, conv.)
		TOTAL		58	57
		Proposed participation of village	Village	Socio-economic 3	Socio-economic 1
		Research site criteria (farm or research centre)			
		Farmer name			
10	H	Accessibility for staff*/villagers	low (3) medium (6) | accessibility high (9)	6 9	6 9
11	H	Inclusion of variety*/short season vegetable crops in rotational mix, preferably high value crops	occasionally (3) often (6) | includes always (9)	3 9	3 9
12	H	Farmer willing to participate for up to 4 years	partially (3) mostly (6) | willing very (9)	9	9
13	H	Flat land (for uniform irrigation water pressure and distribution)	some low slope (3) mostly no slope (6) no slope (9)	6	9
14	H	Soil exhibits constraints relevant to focus of project	one (3) some (6) | constraints many (9)	3	6
15	H	Vegetable production is main dry season enterprise- wet season rice production should be avoided where possible	rice (3) other (6) | main enterprise dry season vegetable (9)	9	9
16	M	Innovative, progressive, skilled farmer	low (2) medium (4) high (6)	4	4
17	M	Staff available for experimental operations where needed	low (2) medium (4) | availability high (6)	6	6
18	M	Irrigation system, preferably drip	Hand water (2) Furrow, sprinkler, soaker hose, drip/trickle tape (4) pressure compensated drip (6)	2	2

No.	Priority	Criteria	Scoring scales	Site 1	Site 2
19	M	Market accessibility for value chain aspects of project	low (2) moderate (4) │accessibility good (6)	6	6
20	M	Land area available for trial plots e.g. minimum 1200m^2 (approx. 40mx30m), maximum 3200 m^2 (approx. 40mx80m)	less than minimum (2) about minimum (4) about maximum (6)	4	6
21	M	Meets ASEM criteria below - Siem Reap only	some (2) many (4) │criteria all (6)	NA	NA
22	L	Mobile phone reception	poor (1) moderate (2) │reception good (3)	3	3
		TOTAL		79	87
		Proposed participation of site (Text in brackets are secondary suggestions)	Experiment	Irrigation (Nutrients/pH)	Organic matter
		Proposed participation of site	Demonstration		

Priority code: L=low, M=medium, H=high

11.2 Appendix 2. Participatory Impact Pathway Analysis and Monitoring and Evaluation Plan

Double click on the text box link below to access the project Monitoring and Evaluation Plan; Ives, S. and Jones, S. (2019) SMCN_2014_088 MEL Framework. Update 20190320. Working document.

Monitoring, evaluation & learning Framework

(ACIAR SMCN/2014/088: Improving soil and water management in vegetable production in Lao PDR and Cambodia)

- (i) **Proposed focus of the evaluation and specific evaluation activities**
- (ii) **Overall project logic**
- (iii) **Indicators of progress towards outputs and outcomes**
- (iv) **Questions/comments…..**

Double click on the text box link below to access the Participatory Impact Pathways Analysis Report: Starasts, A. (2019) ACIAR SMCN 2014 088 Participatory Impact Pathways Analysis March 2019. Report

Australian Government
Australian Centre for International Agricultural Research

Participatory Impact Pathways (PIPA)

project	**Integrating soil and water management in vegetable production in Lao PDR and Cambodia** **Update March 2019**
project number	**SMCN/2014/088**
Author/s	Ann Starasts (University of Southern Queensland)

11.3 Appendix 3. Comparison of irrigation scheduling approaches

Different irrigation scheduling methods, whether weather, soil moisture or plant-based, have advantages and limitations that affect their suitability for a particular system and environment. Suitability of a method is determined by cost, accessibility, practicality, level of required knowledge, usability and accuracy of the method. The following table compares the advantages and limitations of scheduling methods according to the literature.

Table 42. Advantages and limitations of different irrigation scheduling techniques

Irrigation scheduling Method	Advantages	Sources	Limitations	Sources
Weather based Methods				
i) *FAO Penman-Monteith Method*	• Widely used and researched • Doesn't require inputs • Quite accurate	(Allen *et al.* 1998);	• Complicated equation • Requires access to weather data • Requires access to weather station– most useful with weather station is close by	(Allen *et al.* 1998)
ii) *Class A Pan Evaporation Method*	• High degree of adaptability • High degree of useability • Relatively easy to access / determine required weather data • Robust under a variety of conditions • Can simply indicate how much water to apply • Resultant system for plant, water, and climate interrelationship • Can be used as substitute to Penman-Monteith method	(Imtiyaz *et al.* 2000); (Smajstrla *et al.* 2000); (Pardossi and Incrocci 2011); (Jones 2004); (Ertek *et al.* 2006)	• Lower accuracy, particularly compared to direct soil moisture measurements • Operators require moderate to high level of technical capacity • Can be expensive ~ $500 • Difficult to transport • Requires specific structural materials • Requires access to weather data from nearby weather station • Requires estimates of crop coefficients which can be difficult to obtain	(Pardossi and Incrocci 2011); (Jones 2004); (Hartz 1999); (Smajstrla *et al.* 2000); (Rashad and Omran 2012); (Simmonne *et al.* 1992)

Irrigation scheduling Method	Advantages	Sources	Limitations	Sources
			• Calculating ET can be difficult • Regular recalibration needed • Doesn't account for system/ field non-uniformity • Class A pans cannot directly predict water usage of crops	
iii) Mini pan Evaporation Method	• Using inputs available to farmers • Cost effective • High degree of usability • Practical • Versatile • Easily transportable • Robust under a variety of conditions • Can simply indicate how much water to apply • Resultant system for plant, water, and climate interrelationship • Can be used as substitute to Penman-Monteith method	(Rashad and Omran 2012); (Simmonne *et al.* 1992); (Sugar Research Australia 2014); (Vinh *et al.* 2015)	• Might not be highly accurate • Correct calibration required for each pan • Requires access to weather data from nearby weather station • Requires estimates of crop coefficients which can be difficult to obtain • Calculating ET can be difficult • Regular recalibration needed • Doesn't account for system/ field non-uniformity • Pans cannot directly predict water usage of crops	(Rashad and Omran 2012); (Simmonne *et al.* 1992)
Soil Moisture Sensors				
i) Volumetric Including: *Neutron Probes, Time Domain Transmissivity, Capacitance sensors*	• Accurate • Easy to log and set up • Good response time • Don't require much maintenance • Can provide continuous readings through automation	(Peters 2012); (Munoz-Carpena and Dukes 2005); (Pardossi and Incrocci 2011)	• Require many sensors in one field for soil heterogeneity • Expensive between $110–$4500 per sensor • Vary in accuracy depending on type of sensor and model	(Peters 2012); (Ganjegunte, Sheng and Clark 2012);

Irrigation scheduling Method	Advantages	Sources	Limitations	Sources
			• Require site specific calibration	
ii) Soil Moisture Tension Including: *Tensiometer, Granular matrix sensors*	• High precision • Easy to apply in practice • Can indicate 'how much' water to apply • Less expensive than most volumetric • Some are readily automated	(Peters 2012); (Jones 2004); (Pardossi and Incrocci 2011)	• Highly variable output • Require site specific calibration • Require many sensors in one field for soil heterogeneity • Difficult to select position that is representative of root zine (important for vegetable production) • Maintenance issues • Require site specific calibration • Relatively narrow working range of soil water potential • Difficulty coping with spatial variability of soil water properties and irrigation water distribution • Moderately expensive $40 - $80 per sensor	(Jones 2004); (Peters 2012); (Ganjegunte, Sheng and Clark 2012); (Munoz-Carpena and Dukes 2005); (Fereres, Goldhamer and Parsons 2003)
iii) Hand Feel	• Simple • High level of practicality • No costs involved	(Martin 2009);	• Subjective • Not highly accurate • Requires experience	(Martin 2009);
Plant-Based Sensing				
(Grouping all methods together – for more in-depth on each individual sensor readers refer to Adeymey *et al.* 2017 and Jones 2004)	• Direct measurement of plant response to soil moisture level • Measure of plants response to climate	(Pardossi and Incrocci 2011); (Jones 2004)	• Difficult application • Not widely researched • Scarcely used	(Pardossi and Incrocci 2011); (Jones 2004); (Fereres, Goldhamer and Parsons 2003)

Irrigation scheduling Method	Advantages	Sources	Limitations	Sources
	• Based on plant response to water deficit rather than measuring soil moisture content • Measures plant stress directly • Highly sensitive • Integrates environmental effects • Considers irrigation needs of individual plants		• Requires in-depth knowledge of plant physiology • Using directly measured plant water status in irrigation management is hampered by the difficulty of relating the measurements to timing and amount of irrigation • Commercial adoption of technologies and plant-based sensors requires knowledge of how the measurements impact crop yield • Complicated because species and processes differ in their sensitivity to water stress • Some plant-based sensors are not automated so difficult to frequently conduct these tests	

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11.4 Appendix 4. Trials and treatments across seasons

Table 43. Nominated sites for the dry season 2016/17 in Lao, PDR, and Cambodia

No	Site Code	District, Commune, Village	Type of Experiment	Treatment	Comments
Lao PDR					
1	Vientiane 01	Xaithany, Pakxapkao	Replicated	Organic matter	
2	Vientiane 02	Xaithany, Pakxapkao	Replicated	Organic matter	
3	Vientiane 03	Xaithany, Nasala	Replicated	fertiliser	
4	Vientiane 05	Hadxaifong, Huaha	Replicated	fertliser	
5	Vientiane 06	Hadxaifong, Huaha	Replicated	fertliser	
1	Champasak 01	Phunthong, Nongbua	Replicated	NPK experiment	
2	Champasak 02	Phunthong, Donley	Replicated	NPK experiment	
3	Champasak 05	Paksong, Thongset	Replicated	NPK experiment	
Cambodia					
1	Kampot 01	Tuek Chhou, Koun Sat	Replicated	Fertliser	weather problems, but some yield collected
2	Kampot 04	Chhouk, Trapeang Chrey	Demo	Fertliser	rained out
1	Siem Reap 01	Pok, Krobierial, Popis	Replicated	Fertiliser x lime x irrigation	
2	Siem Reap 03	Prasat Bakong, Kontrang, Ta Trav	Demo	Lime	

Table 44. Nominated sites for the dry season 2017/18 in Lao, PDR, and Cambodia

Site Code	District, Commune, Village	Type of Experiment	Treatment	Comments
Lao PDR				
Vientiane 01	Xaithany, Pakxapkao	Demo	3 x lime rates with farmer practice NPK	
Vientiane 02	Xaithany, Pakxapkao			Nothing on this site
Vientiane 03	NUoL	Replicated	lime x irrigation scheduling experiment with lettuce	
Vientiane 04	HRC	Replicated	OM experiment x 2 crops (lettuce & spring onion	
Vientiane 05	Hadxaifong, Huaha	Demo	lime and NPK in celery	not done
Vientiane 06	Hadxaifong, Huaha	Replicated	Organic Matter, lettuce	
Champasak 01	Phunthong, Nongbua	Demo	Lime	not done
Champasak 02	Phunthong, Donley	Demo	Irrigation scheduling	not done
Champasak 03	Paksong, 35 km, NAFRI Southern Lao Research Station	Replicated	lime and NPK in broccoli	
Champasak 04	Paksong, Thongset, Lao-Viet Research Farm	Replicated	irrigation scheduling experiment with broccoli	Abandoned, although some plant data collected.
Champasak 05	Paksong, Thongset	Replicated	lime and NPK in broccoli	Trial completely overgrown with weeds. Plant growth data recorded.
Cambodia				
Kampot 01	Tuek Chhou, Koun Sat	Demo	lime	
Kampot 02	Tuek Chhou, Koun Sat	Demo	Lime x 4 rates	abandoned after plant loss due to rain
Kampot 03	Chhouk, Trapeang Chrey	Demo	Lime x 4 rates	
Kampot 04	Chhouk, Trapeang Chrey	Demo	Lime x 4 rates	
Kampot 05	Chhouk, Trapeang Chrey	Demo	Nutrient x 2 rates, lime x 2 rates	Abandoned due to losses from weather and insects.
Kampot 06	Chhouk / Chhouk Trapeang Chrey	Demo	Lime x 4 rates	Abandoned due to losses from weather and insects.
Siem Reap 01	Pok, Krobierial, Popis	Demo	Lime x 4 rates with two successive crops	Second crop abandoned.
Siem Reap 02	Tuek Vil Experiment Station, Tuek Vil, Brey Thmeym	Replicated	Irrigation x lime experiment	Abandoned due to insects, rain damage and weed pressure.
Siem Reap 03	Prasat Bakong, Kontrang, Ta Travm	Demo	Lime x 4 rates with two successive crops	1st crop good result, 2nd crop had rain damage.
Siem Reap 04	Prasat Bakong, Kontrang, Ta Trav	Demo	Lime x 4 rates with two successive crops	
Siem Reap 05	Prasat Bakong, Kontrang, Ta Trav	Demo	Nutrient x 2 rates, lime x 2 rates, two successive crops	

Table 45. Nominated sites for the dry season 2018/19 in Lao, PDR, and Cambodia

No.		Village-Commune-District	Type of Experiment	Treatments	Crop 1	Crop 2	comment
Lao PDR							
	Vientiane municipality						
1	Vientiane 01	Paksapkao / / Xaithany	Demo	Lime	Lettuce	Lettuce	
2	Vientiane 02	Paksapkao / / Xaithany	Demo	Lime x NPK	Lettuce	Lettuce	
3	Vientiane 05	Huaha / / Hadxaifong	Replicated	Lime x NPK	Bok Choy	Bok choy	
4	Vientiane 06	Huaha / / Hadxaifong	Replicated	Organic fertiliser		Coriander	
5	Vientiane 07	Nabong / / Xaithany	Replicated	Lime x NPK x Irrigation	Lettuce		
6	Vientiane 08	Haddokkeo / / Hadxaifong	Replicated	Organic fertiliser	Lettuce Spring Onion	Lettuce Spring Onion	
	Champasack province						
1	Champasak 01	Nong boua / / Phonethong	Demo	Fertiliser	Spring onion	Lettuce	
2	Champasak 02	Donelai / / Phonethong	Demo	Fertiliser	Lettuce	Lettuce	
3	Champasak 03	Etou / / Paksong	Replicated	Fertiliser & Lime	Broccoli	Broccoli	Crop failed
4	Champasak 04	Nonghine / / Paksong	Replicated	Fertiliser & Lime	Broccoli	Broccoli	Crop failed
5	Champasak 06	Banlieng / / Paksong	Demo	Fertiliser		Broccoli	
Cambodia							
	Siem Reap province						
1		/ Krabei Riel / Siem Reap	Demo	Lime rates	Bok choy		
2		/ Krabei Riel / Siem Reap	Demo	Lime rates	Bok choy		
3		Ta Trav / Kantreang / Prasat Bakong	Demo	Lime rates	Bok choy		
4		/ Krabei Riel / Siem Reap	Demo	Lime x NPK x Irrigation	Bok choy		
5		Ta Trav / Kantreang / Prasat Bakong	Demo	Lime x NPK x Irrigation	Bok choy		
6		Ta Trav / Kantreang / Prasat Bakong	Demo	Lime x NPK x Irrigation	Bok choy		
	Kampot Province						
1		Prey Ben / Sat Pong / Chhuk	Demo	Lime rates	Mustard green		
2		Prey Ben / Sat Pong / Chhuk	Demo	Lime rates	Mustard green		
3		Prey Ben / Sat Pong / Chhuk	Demo	Lime rates	Mustard green		
4		Prey Ben / Sat Pong / Chhuk	Demo	Lime x NPK x Irrigation	Mustard green		
5		Prey Ben / Sat Pong / Chhuk	Demo	Lime x NPK x Irrigation	Mustard green		
6		Prey Ben / Sat Pong / Chhuk	Demo	Lime x NPK x Irrigation	Mustard green		