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Conservation Agriculture and Sustainable Intensification of Smallholder Farming Systems in Pacific Countries as a Pathway to Transformational Climate Change Adaptation and Reducing GHG Emissions

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1 Acknowledgments

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Fa'afetai tele lava to the Project Advisory Group members from Samoa, and Malo 'aupito to the Project Advisory Group members from Tonga.

The focus group discussions were facilitated by highly experienced agricultural specialists – by staff of USP and the National University of Samoa in Samoa, and by Taniela Hoponoa, of UN FAO in Tonga. Their valuable input to the project is gratefully acknowledged. Special mention is made with appreciation of Soane Patolo of MORDI TT as a strong contributor to this report.

Declaration of Interest

No potential conflict of interest was reported by the authors.

2 Executive summary

There is an opportunity and an urgent need for transformational change of the current farming systems in Pacific Island Countries (PIC) to increase food and nutritional security, to be better adapted to climate change and to be less emissive of greenhouse gases. Substantial global evidence indicates that Conservation Agriculture and Sustainable Intensification (CASI) systems are better adapted, but their effectiveness in PIC is yet to be fully evaluated. The overall aim of this Small Research Activity (SRA) was to undertake a targeted assessment to explore the opportunities for implementing CASI in smallholder farming systems as an adaptive and potentially transformational climate change response in PIC. This SRA was a Proof of Concept which identified and evaluated the research, technological, social and policy interventions required for future implementation and scaling of these more regenerative agri-food systems. It also identified key research and development sites for future work to compare the performance of CASI practices with the current commonly used systems.

This SRA was a joint effort between Australian (The University of Melbourne) and New Zealand scientists (Lincoln University) and scientific partners in Samoa and Tonga, the University of the South Pacific, and The Pacific Community (SPC) and the in-country industry partners such as Samoa Farmers Association, and MORDI TT. The processes of project management put in place for this SRA became an exemplar of ways to deliver a project during the pandemic through effective planning, good organisation, hard work, and goodwill. The methodology in this SRA addressed a series of clearly defined research questions that collectively investigated, developed, and weighed CASI practices in selected systems for small holder farmers that provide options for increasing profitability and productivity, as well as emissions management and mitigation, and adaptation to climate change (incremental and transformational).

Four farming systems across two Pacific Island countries - Samoa (Integrated crop-livestock and Taro-based root crop farming systems) and Tonga (Traditional mixed farming and Intensive monocropping systems) were selected to study the potential benefits of implementing CASI. A mixed-methods approach was employed as part of a convergent parallel design to collect and analyse data. Qualitative data was collected from primary and secondary sources. Quantitative data was collected partly from the focus group discussions and personal interviews (included both male and female farmers) and partly from secondary data sources through literature review, and strengths, weaknesses, opportunities, and threats (SWOT) analysis (covering-biophysical factors; social, institutional, and gender factors).

This data provided insights into a typical farm, crops grown and various on-farm, off-farm practices; gendered roles and responsibilities; access to and control of farm resources by women and men in a farm household; access to various agricultural inputs and sources of information that aid farmers in production and marketing.

This SRA involved creation of two Theories of Change (ToC). The first to guide this SRA (SRA ToC) and the second as an activity to create the pathway for a full CASI proposal. The goal of this SRA ToC was to understand the current farming systems in Samoa and Tonga and then build the outline and pathway for development of the full CASI proposal. This SRA provides detailed information to justify the proposed interventions to develop a CASI system that brings livelihood improvements to communities in Samoa and Tonga.

Based on the current challenges identified in the four farming systems, the best possible synergetic CASI interventions and their combinations which should be validated under field conditions include:

Integrated Crop-Livestock Systems Samoa: best genetic materials (crops and livestock) being tested with nutrient cycling to minimise reliance on synthetic inputs and to improve soil health.

Taro-based root crop farming systems in Samoa: best taro genetic materials to be tested with legumes being incorporated as rotational cover crops during fallow period along with testing of integrated pest and water management options.

Traditional mixed farming systems and intensive monocropping systems in Tonga: no-till/minimum till practice with best crop genetic materials to be tested with legumes being incorporated as rotational cover crops during fallow period along with testing of integrated pest and water management options.

Conclusions and recommendations

It is concluded that CASI has the potential to provide substantial and multiple benefits to all of the target farming systems of this SRA and to farming systems generally in Pacific Island Countries. These benefits include productivity, financial, environmental, social - especially related to gender equality - resilience to climate change, and greenhouse gas emissiveness.

Recommendation 1: It is recommended that additional resources be directed to the processes of field-validation – at research sites and on-farm - for implementing CASI in Pacific Island Countries, including but not limited to project CROP/2020/186 currently under consideration by ACIAR.

Recommendation 2: It is recommended that any further work utilises the significant new partnerships and networks formed in this SRA. This includes effective engagement with in-country farmer representatives, industry and research project partners at all steps in any new work.

Recommendation 3: It is recommended that any further work continues to focus immediately on Samoa and Tonga, and that new opportunities be explored to broaden application of CASI to other Pacific Island Countries, possibly including through the channels of the Koronivia Joint Working Group on Agriculture, and other potential funding organisations.

Recommendation 4: It is recommended that the learnings of this SRA and any further CASI projects are closely aligned with agricultural education and training providers in the Pacific Islands region, especially but not limited to USP. In the short term this could include post-graduate candidatures for field testing of CASI principles in Samoa and Tonga, and in the medium to long term, incorporation of the new knowledge into undergraduate and postgraduate courses as well as industry training.

3 Background

Food and nutritional security under climate change is a major challenge for Pacific Island Countries. As Bell et al. (2016) have stated:

> ‘The peoples of the Pacific region live across a vast swathe of the world’s largest ocean, mostly on isolated islands and atolls. The region includes countries that are highly vulnerable to the effects of climate change and natural disasters. Climate change in Pacific Island Countries and territories is projected to have significant impacts, including rising sea-levels, more violent tropical cyclones, floods, and droughts.
>
> ’Both staple food crops - such as taro, rice and sweet potato - and high value cash crops - such as tomato, mango and papaya - are predicted to be moderately to strongly impacted by future climate change. Impacts on livestock are predicted to be more variable depending on types and breeds.’

ACIAR funded this SRA to undertake a targeted assessment of opportunities for the implementation of **Conservation Agriculture and Sustainable Intensification (CASI)** in selected smallholder farming systems in Samoa and Tonga. It was set up to build on previous ACIAR projects on *Conservation Agriculture and Sustainable Intensification* (CASI) delivered successfully in other parts of the world, as comprehensively reviewed by Dixon et al. (2019).

The assessment in this SRA is aimed at providing guidance on the potential of CASI to provide a range of benefits including (1) increase in nutritious food production (2) increase in farmer profitability (3) social benefits, (4) adaptation options to strengthen resilience against the ever-increasing risks of climate change, and (5) reductions in greenhouse gas emissions. While the specific target of the SRA is smallholder farms in Samoa and Tonga, the SRA was also positioned to provide guidance on the potential of CASI to provide benefits in Pacific Island Countries more generally.

CASI is based on five complementary components (Reeves 2020) that when acting together provide greater benefits than the sum of the individual parts acting alone. While each component can separately contribute improvements, it is their integration into sustainable intensification that results in synergistic improvements in productivity, sustainability, and ecosystem health. These components can be summarised as:

1. **Conservation agriculture** - Minimal soil disturbance, the use of surface mulches and crop rotation, and the integrated production of crops, trees and animals;
2. **Healthy soil** - Integrated soil nutrition management, which enhances crop growth, bolsters stress tolerance, and promotes higher input-use efficiency;
3. **Improved crops and varieties** – When targeting smallholder farming systems provides high yield potential, resistance to biotic and abiotic stresses, and higher nutritional quality;
4. **Efficient water management** – Delivers 'more crop per drop', improves labour and energy-use efficiency, and reduces water pollution from agricultural run-off;
5. **Integrated pest management** - Based on good farming practices, more resistant varieties, natural biological enemies of the pests, and judicious use of relatively safer pesticides when necessary.

Jat et al. (2020) has provided substantial evidence that CASI can provide a range of benefits to smallholder farming in countries in other parts of the world – in particular in South-Asian countries. These benefits were summarised by Jat et al. (2020) as:

1. Better response to climate change,
2. Increased production of nutritious food,
3. Increased farm profitability, and
4. Better protection of ecosystems.

The meta-analysis of CASI reported by Jat et al. (2020) was from a massive 9,686 paired research site conducted across South Asia between 2000 and 2018. This study reported a 12-33% reduction in greenhouse gas emissions, a 6% increase in crop yields, a 26% increase in net economic returns, and a 13% increase in water-use efficiency from CASI based systems compared to local farmer practice. Similar, although less comprehensive studies on CASI have been conducted elsewhere with similar conclusions, for instance in Eastern and Southern Africa – as reported by Brown et al. (2017).

These studies give confidence that well-implemented CASI, as demonstrated elsewhere, could potentially also provide multiple benefits to agri-food systems in Pacific Island Countries, but this is yet to be shown. Our ACIAR SRA is commencing this testing and evaluation.

Several research projects, some funded by ACIAR, have addressed some individual components of CASI in Pacific countries. This previous work has provided the foundations for our SRA. Taking the next step and integrating these components into whole CASI systems has been guided by these previous studies.

A new focus on CASI in Pacific Island Countries, with defined impact pathways, could deliver first the on-farm basis for more resilient food systems, and thereby secondly contribute to increasing the options for governments, industries, and communities to implement cost-effective adaptation to climate change and reductions in greenhouse gas emissions, while increasing farm productivity, profitability, and environmental protection (Reeves, 2020).

There is already a consensus in the Pacific Community that 'climate smart' agriculture is a '*worthy and attainable approach to achieving sustainable agriculture by improving the adaptive capacity of member countries to climate change and enhance the resilience of major crops food production systems in the region'* (SPC 2016). In our project, we have chosen to focus on Conservation Agriculture Sustainable Intensification (CASI**).** Given this, how do CASI systems compare to climate smart agriculture? Campbell et al. (2014) made the following statement on this topic:

> 'The 'sustainable intensification' (SI) approach and 'climate-smart agriculture' (CSA) are highly complementary. SI is an essential means of adapting to climate change, also resulting in lower emissions per unit of output. With its emphasis on improving risk management, information flows and local institutions to support adaptive capacity, CSA provides the foundations for incentivising and enabling intensification. But adaptation requires going beyond a narrow intensification lens to include diversified farming systems, local adaptation planning, building responsive governance systems, enhancing leadership skills, and building asset diversity. While SI and CSA are crucial for global food and nutritional security, they are only part of a multi-pronged approach, that includes reducing consumption and waste, building social safety nets, facilitating trade, and enhancing diets.'

As background to this SRA, we wish to 'drill down' further and provide more detail on the climate risks to food and nutritional security as referenced by Bell et al. (2016) and others (e.g. Barnett 2011), and the potential role of CASI to mitigate these risks.

1. Increasing temperature

It is often reported that mean temperatures are expected to rise in countries of the Pacific by around 1.5°C by 2050. The recent IPPC sixth assessment report (2021) alarmingly projects temperature rises steeper than this. In addition, the New Zealand Earth Systems Model (NZESM) has developed scenarios for Shared Socioeconomic Pathways for marine heatwaves in the Pacific. The inevitable regional temperature increase suggests that marine heatwaves will become more intense and more frequent. The impact and loss of marine biodiversity for Small Island Developing States (SIDS) will transfer an increased food security responsibility onto smallholder farmers who will also be challenged by higher temperatures, and the increase in intensity and frequency of storms.

Regardless of the actual rate over coming decades, any such rise in temperatures will unavoidably have substantial impacts on the production of crops (staple and cash) and livestock. Taro, rice and sweet potato are all considered to be at risk, as well as the cash crops, tomato, mango and papaya. Without significant adaptation, these impacts on crop production will have major flow-on effects to future food and nutritional security. Research from other regions of the world has clearly demonstrated that CASI can provide several pathways to adaptation of farming systems to hotter temperatures. Conservation agriculture (CA) includes soil mulching which has been shown to reduce soil temperatures in the root zone of crops, and to increase soil moisture content. In addition, CA has also resulted in reduced crop canopy temperatures (Jat et al. 2008) with resultant increases in crop yields.

An additional essential component of CA is the introduction of more diverse farming systems including crops, forages, livestock, shrubs and trees which have been shown to provide more resilient farming systems less susceptible to climatic shocks, including heatwaves. The use of improved varieties and genetic material is another key feature of CASI, and there is evidence of, for example, taro lines with greater stress tolerance (More et al. 2019).Such material is held by SPC, a key partner in this SRA.

The projection of temperature increases in the coming decades and their deleterious impacts on crop production are clear; and 'business as usual' is not a viable option. Substantial global evidence indicates that CASI systems are better adapted, but their effectiveness in Pacific countries is yet to be evaluated - hence the focus of this SRA to scope the potential.

2. Rainfall

According to Barnett (2011): we know less of the changes in precipitation associated with climate change than those associated with temperature. Ruosteenoja et al. (2003) offer the following range of changes in precipitation for the Southern Pacific relative to period 1961–1990: -3.9% to +3.4% by the 2020s; -8.23% to +6.7% by the 2050s; and -14% to +14.6% by 2080s. However, with precipitation, it is less the mean annual changes, and rather the frequency, intensity, and timing of rainfall events that matter most, particularly given that the region is prone to floods and droughts. In Pacific countries, water for agriculture is almost entirely supplied by rainfall rather than by irrigation systems. More rainfall is expected in summer - which is the wet period in the region anyway, and there may be less rainfall in the already dry months. This has implications for sustaining crops throughout the year. Rainfall events are also likely to be more intense, and possibly less frequent, with implications for flooding and drought events (Lal 2004). Jones et al. (1999) suggest that the intensity of rainfall events may increase by some 20–30%. There are several aspects of CASI that could provide better adaptation of farming systems to these projected changes in rainfall – some of which are already being experienced according to our SPC and USP colleagues – and these include the following:

- Reduced tillage and surface mulches not only reduce soil moisture losses but also help to protect the soil surface from erosion during extreme events.
- The use of a wider range of crops/forages with different planting times and growing periods can help to take advantage of soil water when it is available and to ensure annual production even if one season is disrupted by too little or too much rain.
- CASI provides the means to increase production from existing land areas or from a lesser area, giving the option of focusing production in smaller, more suitable areas less susceptible to flooding or drought.

The overwhelming message from the partners and industry associates leading into this SRA was that CASI systems are urgently needed to help farmers better adapt to the already changing climate.

3. Greenhouse gas emissions

It is essential that any new farming systems should also be less emissive in greenhouse gases. There is good evidence from other parts of the world to show that CASI systems have less global warming potential than traditional farming practices. For instance, Jat et al. (2020) found that these reductions were of the order of 12-33% with the more favourable responses on loamy soils and in maize-wheat systems. Their results were from a very wide range of environments in South Asia, and therefore give some confidence that such figures could be similar in other parts of the world, including in the Pacific.

Overall, it is clear that there is an opportunity, indeed an urgent need, to change current farming systems in Pacific countries to increase food and nutritional security, to be better adapted to climate change and to be less emissive of greenhouse gases. There is an ever-increasing portfolio of published data from many parts of the world on agricultural sustainable intensification - as shown in Figure 1. This provides some compelling evidence that CASI can provide these changes in ways that are a ‘win-win-win’ for farmers, the community and for the environment. The rapid increase in publications on sustainable agricultural intensification (Fig. 1) justifies the emphasis on CASI as a sustainability pathway. This SRA is exploring the applicability of CASI to address the urgent needs of Pacific Island Countries to meet the challenges of future food and nutritional security.

While CASI provides an opportunity and a potential for meeting food demand without further loss of natural ecosystems, some important research gaps remain that need urgent attention if effective implementation is to occur (Cassman and Grassini 2020). The research gaps highlighted by Cassman and Grassini (2020) include the need to better integrate synergistically the components that individually provide improvements into overall comprehensive CASI systems. These research gaps are equally relevant in Pacific Island Countries.

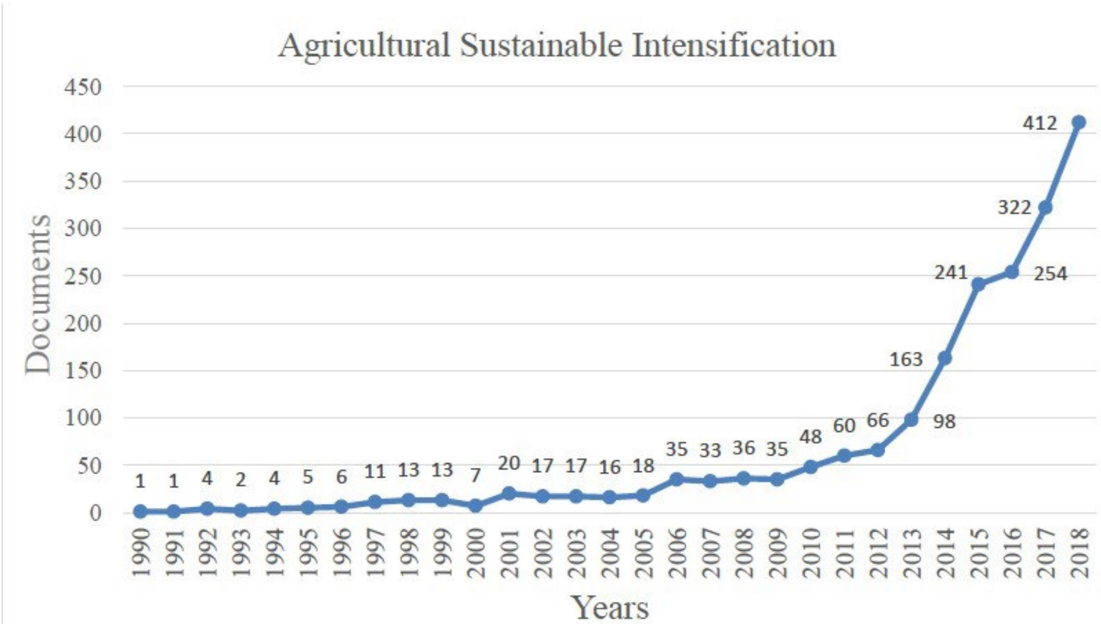


Figure 1. Literature number of agricultural sustainable intensification issued 1990 – 2018. Data Source: Web of Science Core Collection, as taken from Xie et al. 2019.

New CASI research, with defined impact pathways could (and would) also contribute to increasing the options for governments, industries, and communities to implement cost-effective adaptation to climate change and reductions in greenhouse gas emissions - while increasing farm productivity, profitability, and environmental protection (Reeves, 2020).

The SRA was also framed to address the combined priorities of all Pacific Island Countries, as expressed in the outcomes of the first (July 2019) and second (September 2020) workshops of the Koronivia Joint Working Group on Agriculture (KJWA). KJWA was formalised through decision at the 23rd Conference of the Parties to the UNFCCC (COP23). Below is an extract from the Report on the second KJWA workshop that clearly expresses this.

> ‘The Pacific Small Island Developing States agreed that the future topic they want addressed is *How to achieve integrated resilient food production systems in the Pacific SIDS.* Since many of the Pacific SIDs have poor institutional capacity, external technical and financial support for their efforts to improve resilience of their food production systems will be needed.
>
> ‘The Pacific SIDs therefore submit the following as high-priority topics for KJWA. [Headings of first six of nine priorities only listed here, explanation of these priorities is in the KJWA Report.]
>
> 1. Vulnerability of communities and food production systems assessed
> 2. Improved soil health
> 3. Correlation between climate change, pest, disease and transboundary / invasive species, and related impact on food security

4. Adaptation-mitigation co-benefits through reducing emissions of methane and nitrous oxide
5. Water management
6. Improved biodiversity.'

In considering these first six high priority KJWA priorities, we propose that CASI could make an effective contribution to each of them. This is perhaps best summarized in the statement of Cassman and Grassini (2020) as follows:

> 'Regardless of scope and scale, one thing is clear: without SI in the strict sense of increasing crop yields on existing farmland while substantially reducing negative environmental impacts, it will be difficult to achieve a food-secure world without considerable loss of biodiversity and accelerated climate change. Hence the importance of adequate investment and effective R&D prioritization to reach the required degree of SI in food production systems that contribute most to human food supply.

At a national level, the SRA also addressed the national agriculture priorities of Samoa and Tonga – as also reflected in regional, farmer, and industry priorities, including those that are gender sensitive.

This SRA identified and evaluated the research, technological, social and policy interventions required for future implementation and scaling of these more regenerative agri-food systems. It also identified key research and development sites for future work to compare the performance of CASI practices with the current commonly used systems.

4 Objectives

Overall Aim

The overall aim of this SRA as contracted by ACIAR was to undertake a targeted assessment to explore the opportunities for implementing conservation agriculture and sustainable intensification in smallholder farming systems as an adaptive and potentially transformational climate change response in selected countries and regions of the Pacific.

Project Objectives

- Mitigation: For significant agri-food systems in the target region (Pacific), assess the overall potential to reduce greenhouse gas emissions (review of published literature).
- Adaptation: Assess the climate risks to future productivity and profitability of these agri-food systems, including risks from changes in the intensity and frequency of extreme events (review of published literature).
- Produce a typology of agri-food systems based on the assessments of climate opportunities (mitigation) and risks (adaptation), and the relevance to these systems of conservation agriculture based sustainable intensification.
- Assess two critical local agri-food farming systems with regard to their current productivity and potential to respond to climate change, from both mitigation and adaptation perspectives (literature review and analysis by local collaborators). [This was subsequently modified to assessments on four farming systems.]
- Identify and prioritise the male and female farmer/industry needs in relation to these food systems in the context of climate change response, with particular reference to social and gender issues.
- Target the options to improve agri-food/farm systems for productivity and profitability that would also enhance capacities to reduce emissions and adapt to climate change risks (including review of appropriate past ACIAR projects).
- Analyse the implications of adoption of conservation agriculture and sustainable intensification to address identified male and female farmer/industry needs.
- Analyse future options to use available external waste organic matter; options for waste minimisation and reuse; and other components of a more circular agri-food economy.
- Analyse future options for crop/ livestock/product diversification opportunities arising from future climatic variability and climate change.
- Analyse these systems in terms of the predicted impacts from climate change and the likely successful options for adaptive response.

CASI practices are targeted at ‘incremental transformation’ (Kirkegaard 2019) through the continued integration of technologies and practices resulting in progressive adaptation through to the initial stages of transformation (e.g. from all cropping, through mixed farming, through livestock, through to farming systems including crops, forages, livestock, perennial grasses, shrubs, trees, and associated input/output industries). This assessment would include the infrastructure implications for this trajectory.

5 Methodology

The methodology in this SRA addressed a series of clearly defined research questions that collectively investigated, developed, and modelled CASI practices in selected systems for small holder farmers that provide options for increasing profitability and productivity, as well as emissions management and mitigation, and adaptation to climate change (incremental and transformational).

These research questions were:

- For selected agri-food systems in Pacific Island Countries, what are the likely impacts of climate change and associated risks on their future productivity, profitability and sustainability?
- Which CASI practices could best contribute to making these agri-food systems more resilient and less emissive systems?
- What are the required technological, social and policy interventions required to build new agri-food systems which are more resilient, more adapted, and less emissive?
- What will be the key factors in developing, evaluating, implementing and scaling new CASI practices?
- What are the options for the development of bio-based inputs (e.g. composts; biochar); re-cycling and waste reduction; development of more circular agri-food systems?

The core of the project team to deliver the SRA were:

The University of Melbourne:	Tim Reeves - Project lead David Ugalde Dorin Gupta Gayathri Mekala Surinder Singh Chauhan
The University of the South Pacific	Joeli Veitayaki Lau Viliamu Iese
The Pacific Community (SPC)	John Oakeshott Ellen Iramu
Lincoln University, NZ	Rainer Hofmann

There were many other associates in Australia, Samoa, Tonga, Fiji, and New Zealand who contributed to the delivery of the SRA.

The two key in-country partners who provided outstanding guidance, research leadership and research support in the two studied countries, especially during the COVID 19 lockdowns were:

Samoa Farmers Association	Afamasaga Faamatala Toleafoa
MORDI TT	Soane Patolo

The two organisations recognised the value of CASI research project in alignment with their organisations' visions and volunteered to provide more in-country support with the purpose that their farmers and households in Samoa and Tonga will benefit from the research.

The project team met fortnightly, usually for two hours each time, from the start of July 2020 until SRA completion in August 2021 to ensure effective delivery of the SRA. For each meeting, there were always a circulated agenda, minutes of the previous meeting, and agenda papers. All this documentation is available on request. There were additional meetings, planning sessions, and workshops from time-to-time to address specific issues. Between the meetings, the researchers liaised closely with the in-country partners Samoa Farmers Association, MORDI TT, and USP for updates and guidance to ensure agenda items are delivered with inputs from in-country partners.

The team had to work through the COVID-19 pandemic which prevented any international travel. It was able to utilise effective working relationships that had already been established before the SRA was contracted, and these relationships were strengthened and augmented during the SRA. This teamwork ensured strong coordination and collaboration between Australian and New Zealand partners (UoM, LU), in-country partners (USP, SPC), and the in-country industry partners such as Samoa Farmers Association, and MORDI TT. The processes of project management put in place for this SRA became an exemplar of ways to deliver a project during the pandemic through effective planning, good organisation, hard work, and goodwill.

Four farming systems with contrasting characteristics were selected across two Pacific Island Countries as model systems to study the potential benefits of implementing CASI. The farming systems were selected with weekly online and phone call consultations with in-country partners in Samoa and Tonga. Farming systems were selected on the basis of:

1. Farming systems that covered most of the farmers in each country, and hence provided greatest opportunity for the project to deliver high impact and on-the-ground benefits to farmers and their families,

2. Farming systems that are, or have the potential to become, key farming systems for commercial farming, and for CASI interventions to contribute within the commercial environment to improving productivity, improving soil health and reducing emissions of greenhouse gases.

These farming systems were:

1. Integrated crop-livestock farming systems in Samoa
2. Taro-based root crop farming systems in Samoa
3. Traditional mixed farming systems in Tonga
4. Intensive monocropping systems in Tonga

A mixed-methods approach was employed as part of a convergent parallel design to collect and analyse data, which allowed us to collect both qualitative and quantitative data at the same time for comparing, contrasting and triangulating data (after Creswell & Poth, 2016). Qualitative data was collected from primary and secondary sources. Quantitative data was collected partly from the personal interviews and partly from secondary data sources through literature review.

BEST PRACTICE PROJECT CONDUCT DURING COVID-19 PANDEMIC RESTRICTIONS

We believe that the operational and management procedures implemented for the conduct of this SRA represent ‘best practice’ for the conduct of an international research project during the COVID-19 pandemic and wish to reflect on important ‘lessons learned’.

The project was successfully conducted under pandemic restrictions from commencement to completion and the whole execution was run remotely, as even the University of Melbourne researchers were largely unable to meet personally between themselves, and there was no possibility of domestic or international travel.

It is also important noting that the combined in-countries, Australian, and New Zealand CASI project team had never worked together before and in many cases were unknown to each other at the start.

The key elements of our ‘best practice’ were:

- **Fortnightly team meetings** by zoom at the **same time, on the same day of the week** – we conducted 25 team meetings in total. Participation at those team meetings from core members was over 95% - and 100% for most – with illness the only reason for the rare apologies. The meetings were all chaired by the Project Leader.
- **The production of a detailed agenda** for each meeting, supported by **rigorously prepared agenda papers** which were all circulated at least several days before meetings. All these documents are available on request.
- **Standing items on every agenda** to ensure effective reporting and **participation by all team members.**
- **Clear action items** established at end of each meeting.
- Time taken at early meetings to allow thorough **introductions and scene/context setting.** This included presentations by **ACIAR managers** and senior **in-country representatives.**
- **Establishment of Project Advisory Groups** – these provided valuable guidance and also stimulated substantial, enthusiastic in-kind pro-bono support to the project from NGOs, community groups and the private sector.
- The use of **comprehensive and concise templates** to facilitate and structure effective participation in final SRA report writing and future CASI project development.
- The SRA Team took time at each meeting first to **enjoy each other’s company,** and secondly and importantly **to share current personal and professional experiences with respect, support, and congeniality**. These current experiences at times during the pandemic were tough.

Data Collection and analysis

Literature review:

A survey of scholarly sources (journal publications, books, reports, data) was conducted to source both qualitative and quantitative data for the four farming systems. The main aim of this review was to identify the current CASI interventions across the Pacific Island Countries and other parts of the world and to complement the information collected from primary sources in the research. A thematic analysis was done to summarise the key findings. An extensive data base was established and is available for any further studies (see Section 7.8).

Focus group discussions:

A total of five focus group discussions (FGD) that included both male and female farmers were conducted across the two study countries. The main topics that were discussed through the FGD were - conservation agriculture & tillage practices, soil nutrition management, improved crops and varieties, current water management, current pest management, climate change impacts on farm/production, and changing gender roles and responsibilities. The qualitative data from the discussions was analysed using thematic analysis. Thematic analysis is a qualitative data analysis method that involves reading through a data set (such as transcripts from interviews / focus groups) and identifying patterns in meaning across the data. The result is an interpretive analysis of the data communicated through a narrative that presents a coherent story about the data supported by vivid quotes from the interviews (Braun and Clarke 2006). Therefore, no statistical analysis was used to analyse this data. FGDs were conducted in local languages and the transcripts were later translated to English for analysis.

SWOT Analysis:

The first step of a strengths, weaknesses, opportunities and threats (SWOT) analysis of the four farming systems was conducted using secondary information sources with a focus on social, gender, biophysical and institutional issues. In-country partners were also involved in validating the desktop SWOT information. This analysis was then 'road-tested' in the focus group discussions, and with members of the Project Advisory Groups.

Personal Interview Surveys

Personal interviews were conducted with farmers across the four farming systems. The questionnaires for these interviews are available at Supplementary Information, Sections 12.1, 12.2, 12.3, 12.4.

The questionnaire for personal interviews was developed by the research team. For Samoa, interviews were done in Samoan on paper, then translated and used for analysis. For Tonga, NGO MORDI TT converted the questionnaire to the format for the electronic data collection software Kobotoolbox (https://www.kobotoolbox.org/). It also translated the questionnaire into the Tongan language, and MORDI's team of data collectors applied the tool and conducted interviews in the field. All data were extracted in Microsoft Excel and used for the analysis.

This data helped us gain insights into a typical farm, crops grown and various on-farm, off-farm practices; gendered roles and responsibilities; access to and control of farm resources by women and men in a farm household; access to various agricultural inputs and sources of information that aid farmers in production and marketing. All data were gender disaggregated and a gender balance was maintained in the selection of respondents for the interviews and the focus group discussions (see Table 1).

Data from personal interviews were analysed using thematic analysis, frequency distribution tables, percentages. Considering the small sampling size for each farming system, Analysis of

Variance was not performed for this data. A convergent parallel approach combining qualitative and quantitative data sources and analyses from these interviews is shown in Figure 2. Gender analysis was used to examine the roles and responsibilities, access to, and control of resources by women, men and children in a household. The information from this primary data was complemented and triangulated with secondary data from literature review. Figures 3 and 4 present the locations of the farm households that were interviewed for the study in Samoa and Tonga respectively.

Human Research Participants and Ethics Approval

The personal interview surveys involved interviewing human subjects. Ethics approval was obtained through the Research Ethics Group of The University of The South Pacific (Samoa Campus). A plain language statement was provided to interview participants which explained the project and outlined the confidentiality processes and use of data as approved by the Research Ethics Group. We confirm that all the research participants provided appropriate informed consent upon signing a consent form. All ethics approval documents can be provided on request.

Selection of Respondents

Selection of the key informants for personal interviews and the Focus Group Discussions were done by the in-country partners in consultations with the researchers. For Samoa, farmers were selected by the USP team at the Samoa campus and the School of Agriculture and Food Technology. For Tonga, selection was done by MORDI TT and USP based on their local knowledge of the diversity (gender, age) and expertise of farmers.

Based on the characteristics of the population and the objective of the study, a purposive non-probability sampling method was used where respondent farmers were chosen by researchers based on known farmer types in the area and prior experience in the study area. Personal interviews were conducted with 85 participant farmers (42% female and 58% male) across the four farming systems (see Table 1).

The questionnaires are available (see Section 12, Supplementary Information). These questionnaires were pre-tested for clarity and completeness and were further refined where necessary..

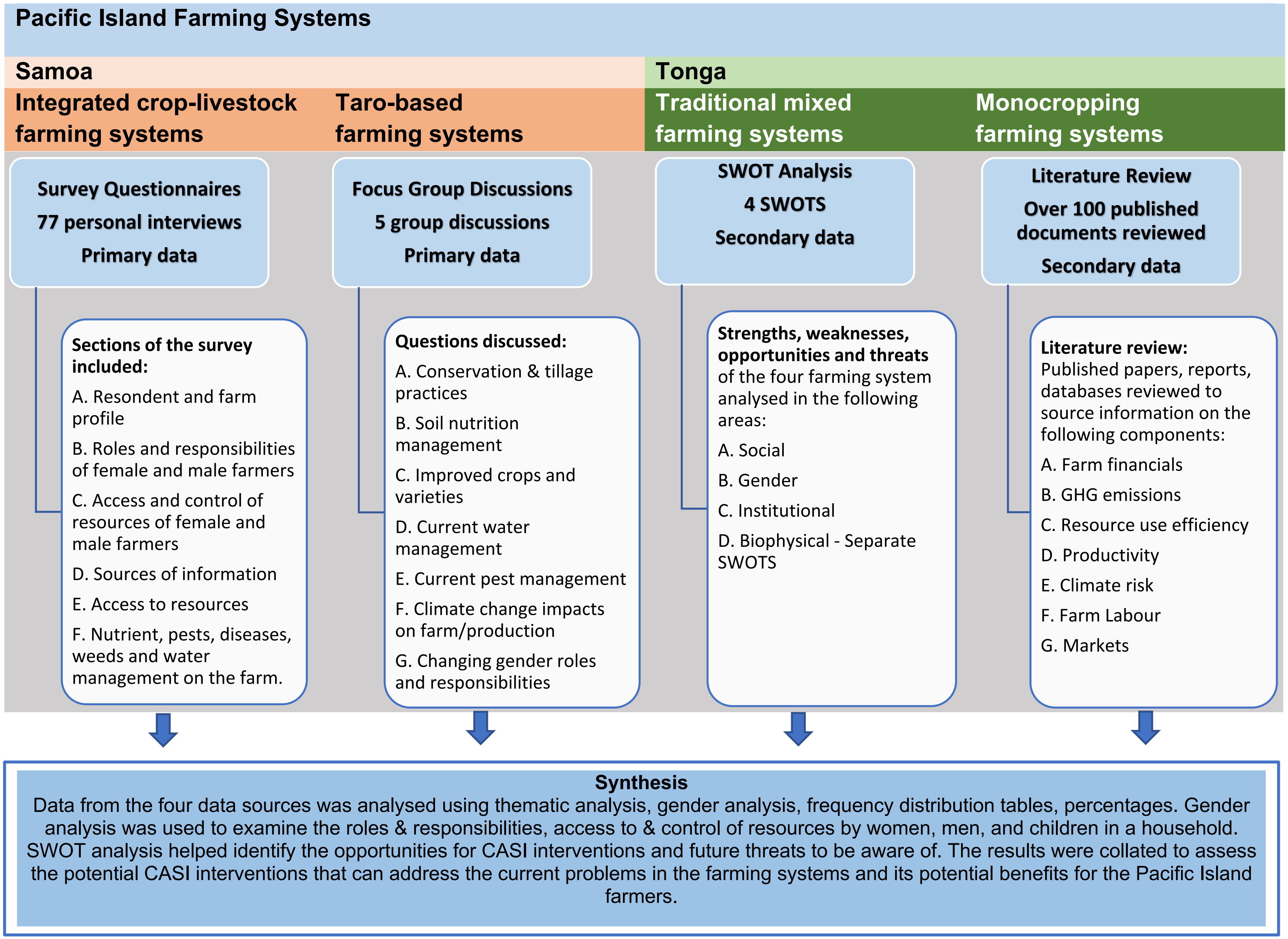
Table 1. Methods used for the four farming systems in Samoa and Tonga

Farming systems	Personal Interviews		Focus Group Discussions	SWOT Analyses[1]
	Female	Male		
Integrated crop-livestock	7	10	Two	Two SWOT analyses
Taro-based	10	10	One	Two SWOT analyses
Traditional mixed	9	18	Two	Two SWOT analyses
Monocropping	10[2]	11[3]		Two SWOT analyses
Sub-total	36	49		
Total	85		Five	Eight SWOT analyses

[1]Two SWOTs were conducted for each farming systems covering (1) Social, gender, institutional aspects and (2) Biophysical aspects

[2] 8 corporate owned 2 family owned; [3]9 corporate owned 2 family owned

Figure 2. A convergent parallel approach combining qualitative and quantitative data sources and analyses



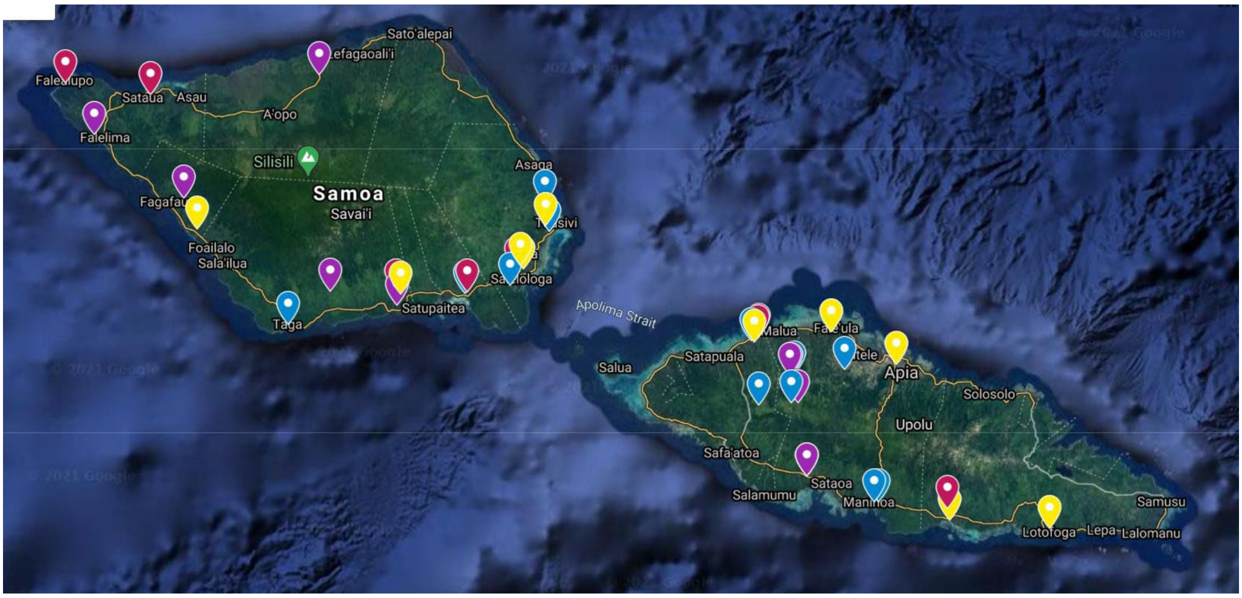


Figure 3. Samoa survey interview locations

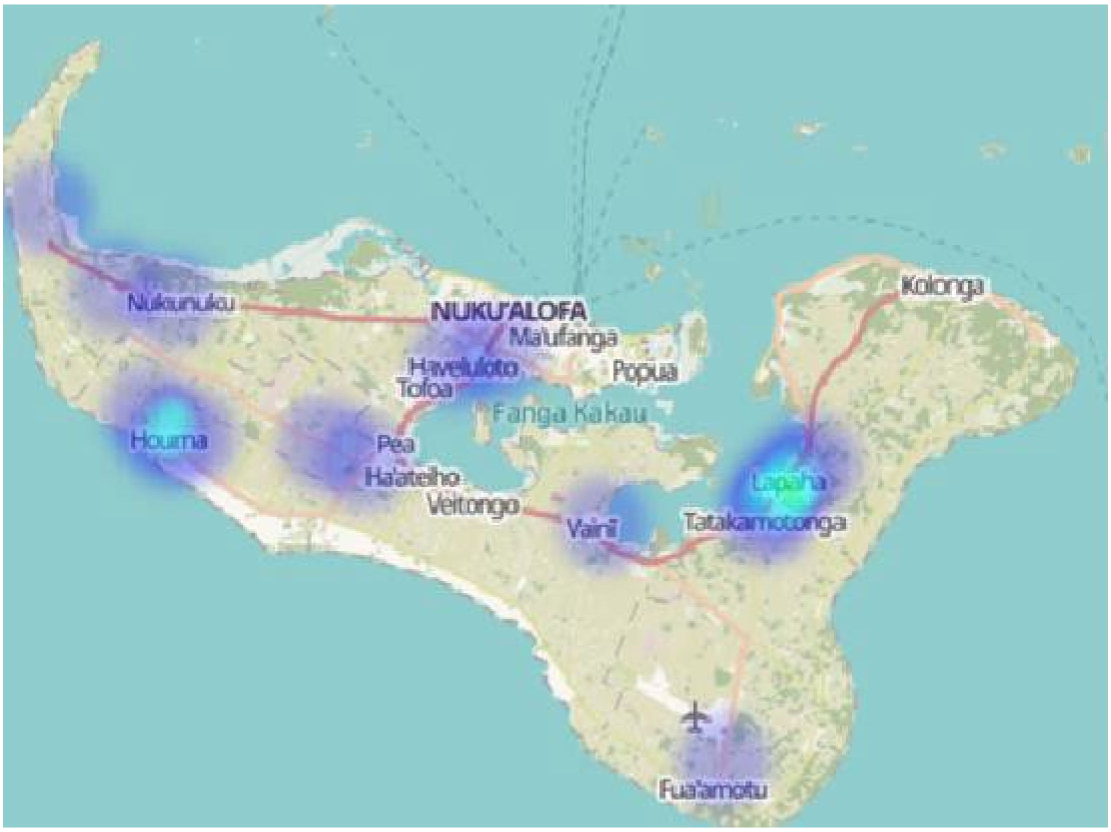


Figure 4. Tonga survey interview locations

6 Achievements against activities and outputs/milestones

This SRA was conducted from July 2020 to June 2021.

All project achievements against activities and outputs/milestones were delivered by the whole project team.

- Leadership, coordination, and research in Australia and New Zealand were delivered by the University of Melbourne, and Lincoln University;
- In-country academic leadership, coordination, and research were delivered by The University of the South Pacific, and the Pacific Community;
- In-country industry leadership, coordination, and research were delivered in Samoa by USP Samoa, the Samoa Farmers Association, and the Samoa Project Advisory Group; and in Tonga by USP Tonga, MORDI TT, and the Tonga Project Advisory Group.

Achievement 1: To develop a theory of change and modelling adoption pathways as the framework for this SRA

No.	Activity	Outputs/ Milestones	Completion Date	Comments
1.1	Develop theory of change as applies to CASI and PICs	Analysis and documentation	June 2021	Achieved jointly PC* and A*
1.2	Pathway to implementation	Analysis and documentation	June 2021	Achieved jointly PC and A
1.3	How research influences actions on the ground	Analysis and documentation	June 2021	Achieved jointly PC and A

*PC = partner country, A = Australia

Achievement 2: To establish Project Advisory Groups and receive in-country guidance, oversight and direction

No.	Activity	Outputs/ Milestones	Completion Date	Comments
2.1	Samoa PAG	Establish Input to SRA	Nov 2020 June 2021	Achieved jointly PC and A; Input received in many ways until SRA completion
2.2	Tonga PAG	Establish Input to SRA	Nov 2020 June 2021	Achieved jointly PC and A; Input received in many ways until SRA completion

PC = partner country, A = Australia

Achievement 3: To analyse implications of CASI for selected target farming systems:

1. ***Samoa: Integrated crop-livestock farming systems***
2. ***Samoa: Taro-based root crop farming systems***
3. ***Tonga: Traditional mixed farming systems***
4. ***Tonga: Intensive monocropping farming systems***

No.	Activity	Outputs/ Milestones	Completion Date	Comments
3.1	Description of farming system	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
3.2	Social and gender factors impacting, and implications for CASI	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
3.3	Analysis of strengths, weaknesses, opportunities, and threats	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
3.4	Challenges and proposed interventions	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis

PC = partner country, A = Australia

Achievement 4: To model impacts of proposed CASI interventions

No.	Activity	Outputs/ Milestones	Completion Date	Comments
4.1	Productivity impacts	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
4.2	Financial impacts	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
4.3	Social impacts	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis

4.4	Environmental impacts	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
4.5	Resilience to climate change	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis
4.6	Greenhouse gas emissiveness	Analysis and documentation	June 2021	Achieved jointly PC and A; Input received from in-country personnel, supplemented with literature analysis

PC = partner country, A = Australia

Achievement 5: To create an on-going information resource base on CASI interventions in Pacific Island Countries

No.	Activity	Outputs/ Milestones	Completion Date	Comments
5.1	Create usable resource base	Compilation and access	June 2021	Achieved jointly PC and A; Particular input from SPC

PC = partner country, A = Australia

Achievement 6: To provide recommendations to ACIAR

No.	Activity	Outputs/ Milestones	Completion Date	Comments
6.1	Provide recommendatio ns	Analysis and documentation	June 2021	Achieved jointly PC and A

PC = partner country, A = Australia

7 Key results and discussion

7.1 Theory of change and modelling adoption pathways as developed and used in this SRA

This SRA undertook a suite of activities to identify and analyse inputs, assumptions, partners, and stakeholders involved in change as relevant to CASI in Pacific Island Countries (PICs) as the foundations for (1) maximising the value of this SRA, (2) designing a larger ACIAR CASI proposal, and (3) progressing change to the next levels of implementation of activities and expected outputs.

This theory of change and the modelling of adoption pathways as developed and used in this project are presented below as follows:

7.1.1 Theory of Change – SRA to Full Project

7.1.2 Pathway to Implementation Within Farming Systems Being Studied and as a 'Seed and Beacon' Across Pacific Island Countries

7.1.3 How Research Influences Actions on the Ground.

7.1.1 Theory of change – SRA to full project

This SRA involved creation of two Theories of Change (ToC). The first to guide this SRA (SRA ToC) and the second as an activity to create the pathway for a full CASI ToC proposal. The goal of this SRA ToC was to understand the current farming systems in Samoa and Tonga and then build the outline and pathway for development of a ToC for a full CASI proposal. This SRA provides detailed information to justify the proposed interventions to develop a CASI system that brings livelihood improvements to communities in Samoa and Tonga. Table 2 shows the SRA ToC and the Goal to achieve an acceptable ACIAR full CASI proposal. The activities were desktop research, interviews, and Focus Group Discussions (FGD) with Samoan and Tongan smallholder farmers. This generated reports that were reviewed at regular project team meetings and endorsed by a cross-sectional representative group of in-country partners. To successfully meet the Goal, the project team also benefitted from ACIAR support and guidance from the inception to the completion of this final SRA report.

Table 2: SRA Theory of Change

Narrative Summary	Verifiable Indicators	Means of Verification	Assumptions
Goal: Full proposal that details farming systems in Samoa and Tonga and potential CASI interventions	SRA Final Report accepted by ACIAR	SRA Final Report, Emails	ACIAR support and guidance from Inputs to Goals
Outcome: In-country partners endorsement	Country Advisory Group Meetings endorsement of reports	Meeting Minutes, emails	Advisory group provides a good representation of local agriculturalist's and farmer's opinions
Outputs: Reports & Surveys	Reports and surveys are reviewed at regular team meetings	Meeting Minutes, emails	Reports and surveys can be completed within the timeframe
Activities/Inputs	· Desktop study · Farmer surveys · Team meetings · Country Advisory Group Mtgs	· Basis for surveys; Reference list · Surveys completed · Fortnightly project team mtgs · Meetings held in Samoa and Tonga	· Quality literature review · Representative group · Availability of team · Representative group

The second ToC activity is for the full CASI project proposal. The ToC was a standing discussion point in the 21 regular project meetings. Outside of these regular meetings, the project team presented a draft ToC to ACIAR on 14 July 2021 which provided valuable input into the ToC. The ToC presented in this SRA for the full CASI proposal is only regarded as a draft until an inclusive workshop is held with the project team, smallholder farmers, and other stakeholders. This workshop will be an activity during the full CASI project inception meeting.

Creation of the ToC required the project team to consider the context of smallholder farmer's (SHF) personal reality, knowledge, and values that guide their decisions. These decisions might be regarded as irrational choices by a 'rational' economist'; however, for SHFs operating within a short-term coping strategy overlaid with family, community, cultural, political, or religious expectations, their decisions are multi-factorial, considered, and can have unexpected outcomes for a project. What one person regards as irrational; another will regard as rational. SHF decisions depend on what they feel they can control, what they think is fair, and what they value. Understanding control, fairness, and values can lead to understanding of the individual priorities and needs. This is a challenge for the initial design of a ToC and required an adaptive approach in the design to capture different SHF priorities, changes, additions, or deletion of activities as the project progressed towards a constant goal.

Development of a ToC designed to be 'people-centric' and support CASI principles required consideration on how to embrace these unexpected human decisions that progress the ToC on a non-linear pathway to reach its goal. CASI has a broad research and development agenda that covers both biophysical and social challenges and requires mixed-methods approaches to capture the qualitative and quantitative data.

A ToC design generally follows a linear pattern of inputs to outputs to outcomes to impacts leading to the goal. Impacts are most likely to occur at the end of the full project or after the life of the project. In our CASI ToC design for the full proposal, the interventions occur in controlled replicated trials (Mother sites) linked to community sites (Baby sites), where Mother site interventions are tailored to local needs and priorities (Snapp, 2002). Therefore, the interactions and choices made by the SHF partners moves our ToC design from a linear to an adaptive approach (Figure 5).

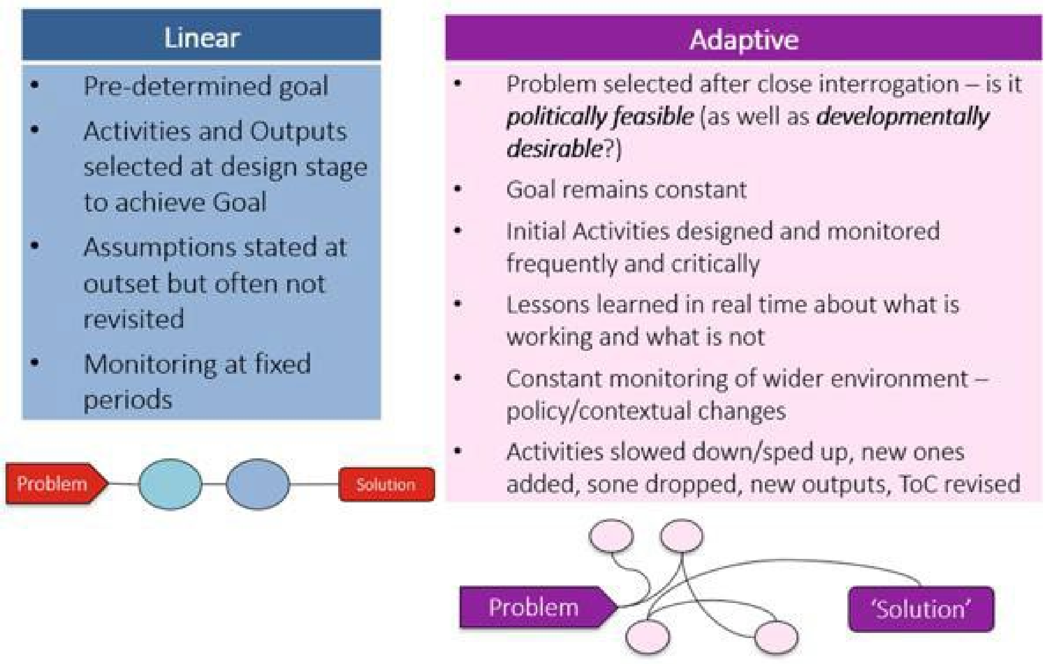


Figure 5: Linear vs Adaptive Approaches (sourced from ACIAR, 2021)

The social challenges have both objective and subjective features that will challenge SHFs in their decisions and choices, and on their capacity to act (agency). These decisions and choices require ongoing reassessment as they develop, collapse, and rebuild, (Figure 6) on their development path (Oakeshott, 2020). The CASI project team, through Participatory Action Research (PAR) and facilitated learning, will co-produce new CASI knowledge between the research team and the SHF. This new knowledge incorporated into the SHF strategy will help keep SHF development from spiralling down. The 'collapse and rebuild' is an important area for the CASI facilitators to ensure motivation and the ongoing development, with the shared risk potentially spread through a group collective action approach, such as an agricultural cluster.

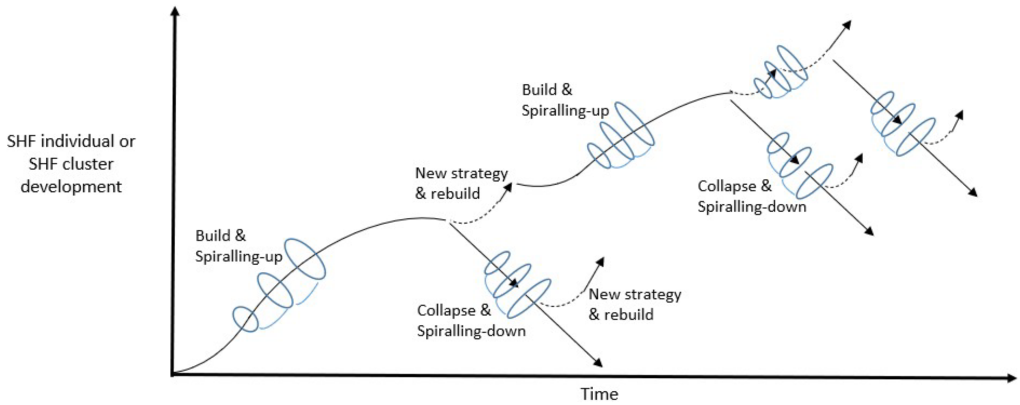


Figure 6: Small Holder Farmers: Develop, Collapse, Rebuild (from Oakeshott 2020)

This non-linear development is incorporated into the CASI ToC through constant feedback and spiralling development, as shown in Figure 7. The constant interplay of socio-economic components with biophysical interventions will progress the ToC as the evidence aligns with the existing social capital of the SHF beneficiaries.

The CASI project team drafted outputs, outcomes, and impacts (Table 3) that show the progression towards benefits the CASI team seek to achieve within and beyond the life of the project. This table is still at a high level and developed out of the literature reviewed, interviews, and FGDs conducted in this SRA. It provides a guide for the implementation of the CASI system, and the draft for the final ToC design that will be undertaken at the inception meeting with all partners providing input. Table 3 is focused on Sustainable Intensification (SI) that is a key part of the CASI approach in the Pacific where access to productive farmland is limited, especially in the atoll countries. Conservation Agriculture (CA) is aimed at reduced tillage practices to decrease the GHG emissions from the soil by utilising soil cover and live mulches and intercropping practices.

SHFs need to cope with issues they immediately face and have a short, planned horizon to manage perturbations, complexities, and uncertainty. This 'coping response' is to make small changes within their current activities and knowledge, and where the outputs or outcomes are predictable, low risk, and losses minimized (Castillo, 1990). To manage the SHF risk aversion, the CASI team will develop SHF agricultural clusters (Baby sites). These clusters move the uncertainty that surrounds individual decisions into a group setting where the group defines and shares the decisions and then the cluster risks can be expressed in terms of probability. This 'Group Polarization' (Aronson, 2010) has shown groups will engage in higher risk activities. This is important for the CASI project team as an individual SHF may not be willing to test interventions, preferring to 'wait and see'. A facilitated cluster is more likely to negotiate for the intervention for incremental changes and hopefully instil confidence within the group. Linked to these 'Baby' sites are the 'Mother' sites that provide empirical evidence to support the decisions of SHF clusters.

Table 3: CASI Outputs, Outcomes, and Impacts

<table>
<tr><th>Outputs</th><th>Outcomes</th><th>Impacts
(Means of Verification)</th><th>Assumptions</th></tr>
<tr>
<td>Increased productivity through identified benefits from:
- Soil management practices
- Improved crops & varieties
- Efficient water management
- Integrated Pest Management (IPM)
- Gender inclusion</td>
<td>- Decreased environmental damage
- Soil health amendments & fertilisers targeted for site context
- Sustainable seed and plant material system operational
- Increase diversity of crops and varieties available
- Investment into irrigation infrastructure and soil moisture management tools
- Inclusive water management decision process operational
- Less use of pesticides within IPM system
- Farm-level biosecurity systems adopted</td>
<td rowspan="4">1. Group: SHF clusters practicing CASI that includes gender inclusivity, farmer to farmer knowledge exchange, collective action. (Report)
2. Individual: increase knowledge and capacity in CASI system implementation through benchmark surveys at inception and again at project completion. (Report)
3. Economic Improvement: Continuous monitoring of SHF cluster accounts payable and received. (Report)
4. Technical: Empirical evidence from Mother trial sites (Report)
5. Climate: Implementation of on-farm circularity and reduced GHG emissions interventions. Contribute to the body of knowledge for Tier 1 Measurement, Reporting, Verification (MRV) for agricultural emissions. (Report)
6. Environment: Increase in local biodiversity through a benchmarking survey at inception and survey again on project completion. (Report)
6. Policies: Policy documents created, influenced, and attributed as evidence of institutionalisation of CASI; especially in regard to gender, food security, climate change and healthy ecosystems for the agriculture sector. (Report)
7. Extension Support: Local Government Units (LGU) and Research organisations embed the CASI systems within their organisation and extension network. (Report)</td>
<td rowspan="4">- Favourable weather and no natural disasters
- CASI system is appropriate for SHFs in Samoa and Tonga
- Partners are engaged and have flexibility to test alternatives
- Value chain’s agents cooperate and readily share information
- Intervention materials are accessible in Small Island Developing States (fertilisers, pesticides, seeds, genetic material, farm inputs)
- Permission for planting is given by landowners
- LGUs have the management support to be fully engaged in the project</td>
</tr>
<tr>
<td>Increased income through identified benefits from:
- Biophysical & socio-economic interventions
- Improved value chains
- Collective action
- Less purchases of external inputs</td>
<td>- Collective action through agricultural clusters widely adopted
- Increase number of supply chain options for SHFs available
- Inclusive and gender sensitive implementation strengthens chain relations</td>
</tr>
<tr>
<td>Climate resilient and environmentally sustainable production system identified through:
- Improved climate measure, verify, & report
- Local biodiversity (flora & fauna) measured
- Local land-use plans created
- Remote weather stations operational</td>
<td>- Soil carbon increases
- Resilient practices for production under higher temperatures with less water are implemented</td>
</tr>
<tr>
<td>Gender-based constraints identified & Inclusive model implemented</td>
<td>- Equitable access to training, skills and knowledge development
- Less work ‘burden’ for men and women
- Changes in division of labour & overall time commitments</td>
</tr>
</table>

A feature of this CASI ToC is the social spiral macro-learning pattern. The spiral model the CASI team has chosen to describe the process involves continual feedback and folds back on itself, then either continues to spiral down or rebuild and progress as a new spiral towards a certain goal. Emery and Flora (2006) termed the process as ‘spiralling up’ to show the importance of social capital as a ‘glue’ for attracting other development assets and factors important for livelihood development. The spiralling fits within the CASI project Theory of Change since it is explicit on continuous feedback, folding back, redevelopment, scaling up and out and deep, as the interventions contribute to progress towards a common goal. This also recognises the ‘people-centric’ approach of CASI that ensures SHFs are embraced in an inclusive design process.

Other social cycle patterns were considered but regarded as less likely to adequately describe the spiralling growth and direction of an agricultural cluster. These other macro-patterns are relevant, and at the end of the project a non-spiral pattern might possibly better describe the final development protectory of an individual cluster or case study. At this stage the spiral is regarded as the best option. Other options considered were:

1. Cyclical – developed as a pattern by Ibn Khaldun in the 14th century (Onder & Ulasan, 2018) that described the rise and fall of sovereign powers through a cycle of birth, growth, maturity, and death. This is like the action learning cycle (theorize, plan, action, reflect) but lacks direction of the CASI chosen spiral design.
2. Linear – Herbert Spencer (Perrin, 1976) developed a theory of social Darwinism that followed a linear-progressive development of human societies
3. Pendulum – Pitirim Sorokin’s (Sorokin, 1937) Pendulum Theory that swung between three social states of materialistic, spiritual, idealistic, and separated by periods of chaos.

The iterative nature of the spiral aligns with the iterative steps within a Participatory Action Research (PAR) approach that will be undertaken within the project. The smallholder farmers in agricultural clusters work in collaboration with the trained facilitators from the University of South Pacific (USP) in Samoa and Mainstreaming Rural Development Innovation (MORDI) in Tonga. Both of these organisations, their facilitators, the project team, and smallholders co-define research questions and activities. Interventions and actions are done together, and knowledge is co-produced (Climate-U, 2021).

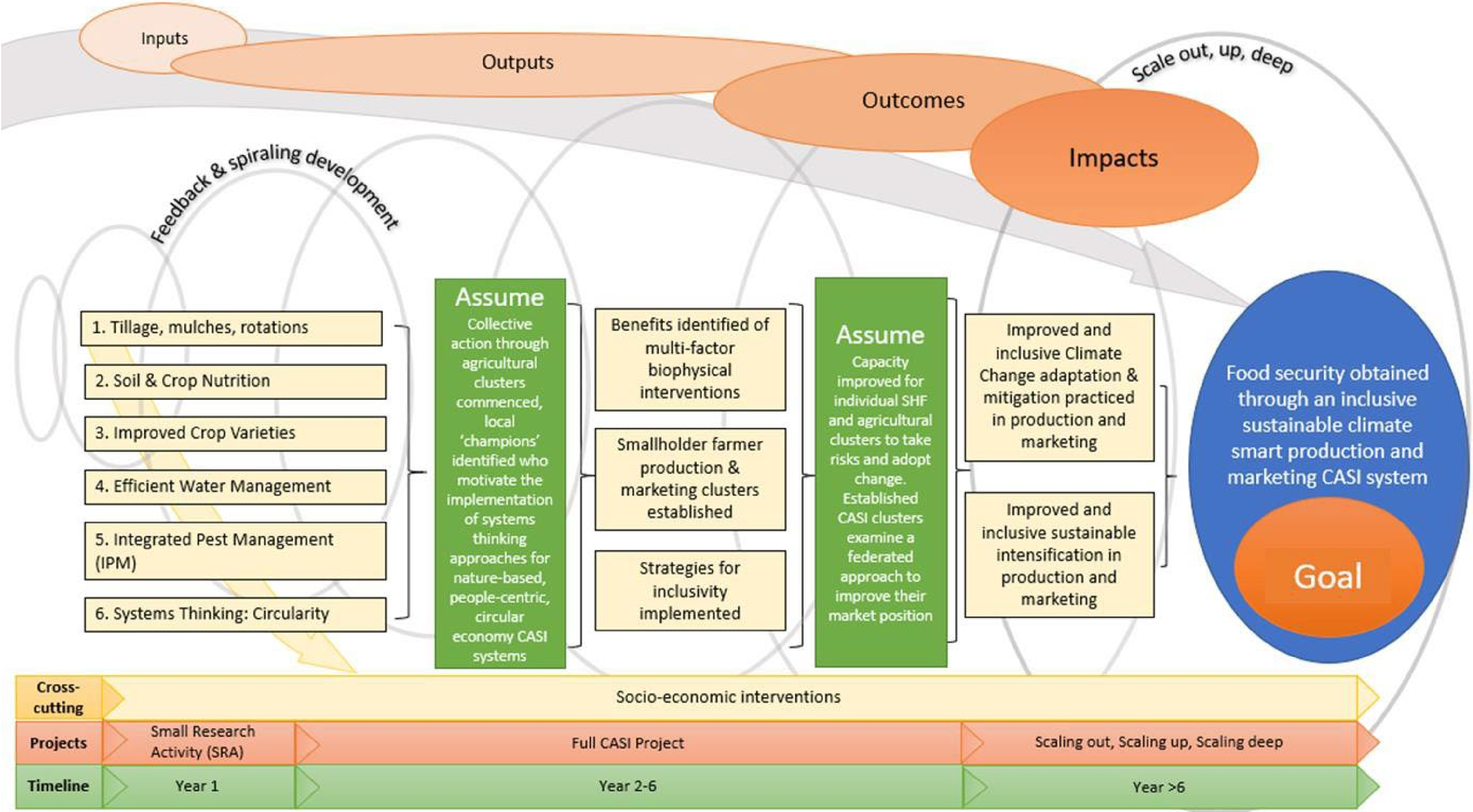


Figure 7: Project Theory of Change

Underpinning the biophysical interventions is the introduction of thinking in systems to help SHF consider their operations as a set of interrelated and dynamic parts and avoid wasted resources, time, and money. In the context of CASI, the systems thinking will actively examine circular economies to create closed-loop systems that minimise use of resource inputs, waste, pollution, carbon emissions, and where waste materials become input for other processes. Achieving this goal of on-farm circular economies is to shift SHF thinking away from a single reductionist analysis of the component ‘parts’ of their on-farm issues to include appreciation of the relationships and interconnectedness of these dynamic ‘parts’ that should be synthesised at the same time. In practice, the feedback loops are important for the development of system maps that provide insights and help realise this circular farm economy. This process of learning can be regarded as Triple-Loop learning or moving technical insights into a function area where SHFs shift their farm-knowledge paradigm and ‘learn how to learn’ within the new paradigm. Single loop learning (Senge, 2006) in the context of SHFs can be regarded as the knowledge and new learning from dealing with daily farming issues within their coping strategy. Double loop learning in this context is the new knowledge that will challenge the SHFs mindset that will reframe their paradigm of their first loop on issues such as Climate Change, food security, gender, environment, biodiversity, and on-farm circular economies. The Triple Loop goes deeper and challenges the SHFs values, goals, and process. There is an interesting social component between sustainability, circular economies, and functional triple loop learning in the SHF context that is relatively new with a growing body of knowledge to which this CASI project has an opportunity to contribute.

The CASI ToC is assumed to follow the path of develop, collapse, rebuild, in a spiralling process involving constant feedback towards the goal. The CASI team will investigate a process for the CASI principles to continue to scale out, up, deep, and impact beyond the life of the project. The team will capture and share the CASI outputs through the case study method (Yin, 2009) to describe the complex CASI system and support further adoption and scale out. Strategies to ‘scale’ CASI depend on many factors, such as, the type of SHF association and the local production and marketing issues they face, access to resources and support services, leadership, partners, opportunities, politics, culture, and social issues (Moore, Riddell, & Vocisano, 2015). Three cross-cutting strategies to ‘scale’ projects are recognized in our ToC, these are scale up, scale out, and scale deep (ibid), shown in Figure 8.

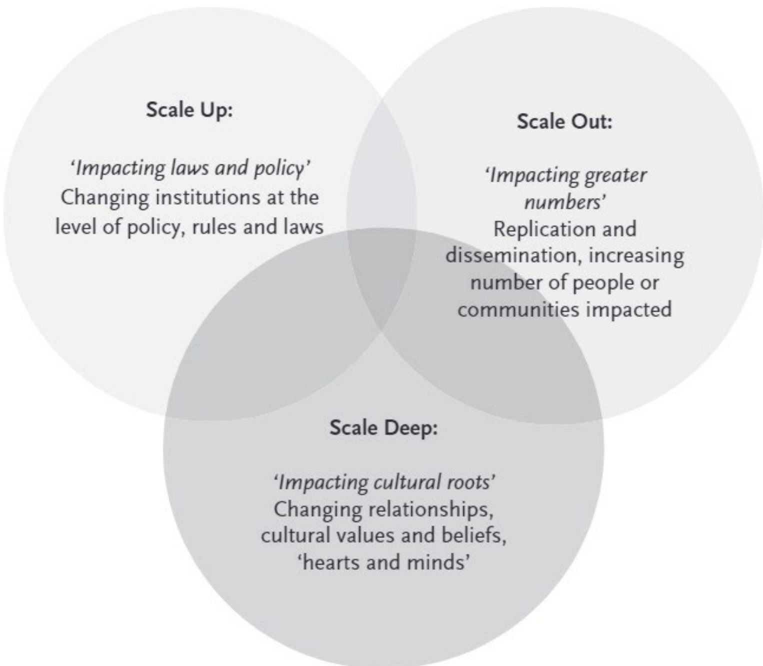


Figure 8: Scale up, Scale out, Scale deep (Moore et al., 2015)

The three CASI strategies to scale out, up, and deep that will operate simultaneously are:

1. Scale out strategy: Replication and expanding the geographic scale and SHF involvement through 'like-minded' farmer associations and community groups. This approach allows SHF associations to adopt the CASI principles and apply these to their own context. The translation to local context involves a lot of work that will require CASI to leverage success into new funding models.
2. Scale up strategy: Refers to the change in policies, laws, and regulations that support the CASI principles. The objective is to link together the SHF associations and community-level policy interventions into a coherent approach that embraces the importance of local context.
3. Scale deep strategy: Ideas, norms, and values are expressed differently in different locations and contexts. The narrative for CASI will need adjusting for the change in context and location. This is especially important for the equitable and inclusive CASI approach to address local beliefs. This is a process of learning to align community culture with the transfer of CASI principles and practices.

The linear nature of the ToC challenges the assumptions for technology adoption for a project like CASI that is designed within a dynamic, multi-dimensional, context specific, and people-centric environment. Identification of the point of 'adoption' of CASI principles is likely to become a challenge due to the iterative nature of the project that reflects the inherent coping strategy and risk aversion of SHFs. CASI is designed as a package of technology that incorporates flexibility for adaptability and is expected to be adopted in components by SHF following the iterative steps within the PAR approach; therefore, adoption represents a continuous process (Tornatzky et al., 1983). No cluster will be the same, and adoption is likely to occur partially and in different ways, and not all at once (ibid).

Wilkinson (2011) has listed some of the complexities behind the term 'adoption':

- Adoption is not a steady state but a continuous process
- Adoption may be partial or incomplete in that a technology might be adopted to different extents on different farms or in different regions
- Adoption may proceed gradually, through increasing extent or intensity of use of a new technology
- A package of related technologies may be adopted in a stepwise manner
- The same technology may be used in different ways on different properties
- Technologies are not static but evolve and are adapted by users to fit different situations
- A technology may be dis-adopted at any time.

Figure 9 shows the adoption pathway described in a recent study by Montes de Oca Munguia, Pannell, lleewellyn, and Stahlmann-Brown (2021), that illustrates from left to right the time from awareness to current use. The horizontal lines are not to scale but represent the different time spans for each stage. This approach can be used in the CASI project to better understand the patterns and progress of adoption for the sites in Samoa and Tonga for the package of CASI technologies. This type of adoption pathway design places emphasis on the adoption measures, that is the dependent variables, with less emphasis on the potential drivers of adoption, or the independent explanatory variables. This approach captures and illustrates the dynamic nature of technology adoption by SHF as a current pattern rather than a binary (adopted, not adopted) actions in a discrete past (Montes de Oca Munguia et al., 2021).

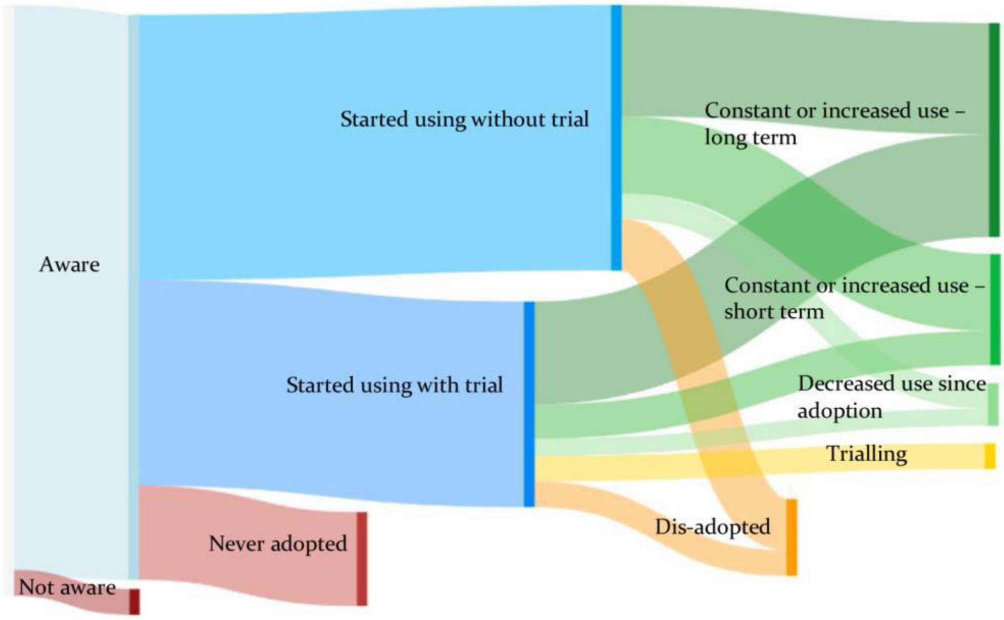


Figure 9: Adoption pathways analysis for agricultural practices
(Montes de Oca Munguia et al., 2021)

This ToC section cannot end without mention of Climate Change (CC) that is a priority in the Pacific region. CASI embraces CC through the introduction of system thinking for circular on-farm economies, reduced tillage to decrease GHG, and sustainable intensification that indirectly will preserve natural landscapes. Climate Change adaptation is a priority, a concern, and a cross-cutting theme within Pacific Island country strategic development plans (Government of Fiji, 2019; Government of Samoa, 2016; Government of the Federated States of Micronesia, 2019; Government of the Republic of the Marshall Islands, 2020; Government of the Solomon Islands, 2020; Government of Tuvalu, 2016; Government of Vanuatu, 2016; Independent State of Papua New Guinea, 2010; Kingdom of Tonga, 2015; Republic of Nauru, 2009; Timor-Leste, 2011). Climate adaptation is linked to multiple forms of knowledge, power, and connections (Climate-U, 2021), and understanding of the local context was reinforced by the IPCC (2018) in its summary for policymakers:

"Education, information, and community approaches, including those that are informed by indigenous knowledge and local knowledge, can accelerate the wide-scale behaviour changes consistent with adapting to and limiting global warming …" (IPCC, 2018).

A study of Climate Change adaptation programs in Indonesia supports this IPCC statement where they showed projects without the engagement of SHFs there is little impact and the fostering of adaptive capacity is limited (Turner-Walker & Anantasari, 2020). This IPCC statement fits well with the CASI approach that will be undertaken in Samoa and Tonga. Starting from the local SHF clusters and the participatory approach for co-production of knowledge, and guided by the direction established in the ToC, other non-target groups will be influenced to adopt behaviour changes for CC adaptation and mitigation, food security, biodiversity protection, gender equity, and livelihood improvement.

This ToC is a living document that requires regular updates to maintain relevance in the dynamic smallholder farmer environment.

7.1.2 Pathway to implementation within farming systems being studied and as a 'seed and beacon' across Pacific Island Countries

People act through communities that from a sociological perspective are regarded as groups of people who share (i) a *location* where they interact, (ii) a *social system* that have organisations through which they interact, and (iii) a *common identity* of norms, values, or interests (Flora, Flora, & Gasteyer, 2018). The three concepts that define a community, *location, social system, common identity*, are changing as globalisation reduces community isolation and new groups and ideas from social media makes them less homogeneous. Even with the impact of the internet and globalisation, communities remain as a locality where people interact and shape their local structures and institutions. These structures and institutions in turn shape the activity of the people who interact with them.

Within rural communities are farming enterprises that have degrees of influence on the livelihoods of their associated communities. This influence is particularly high in less developed rural communities where smallholder agriculture production involves family labour and are critical for food and nutritional security. The focus of the CASI study is these smallholder farming enterprises and how they interact and affect the development of livelihoods of their communities. These farming enterprises under CASI are coordinated into agricultural clusters ('clusters'). These clusters will be created around the proposed 'baby' sites that are extension trials from 'mother' sites in Samoa and Tonga. The 'mother' sites will be hosted by (i) The University of South Pacific (USP) in Samoa, and (ii) The USP and Mainstreaming Rural Development Innovation (MORDI) in Tonga.

Smallholder farmer (SHF) agricultural clusters are defined as:

> *Individual SHFs living in close proximity and collaborating in farm production and marketing enterprise activities of the same or mixed produce in the same supply chains* (adapted from Bosworth & Broun, 1996; Gálvez-Nogales, 2010; USAID, 2008).

The interventions are undertaken in the proposed 'mother and baby' sites. The implementation pathways are through the smallholder agricultural clusters created around the 'baby' sites.

To implement change through CASI in Pacific agriculture farming systems it is preferrable to work with groups that are flexible, have initiative, and are willing to act collectively. A small cluster, composed of 10-15 SHF members, is preferred to ensure coercion exists to manage 'free-riders' and self-interested individuals not working to achieve common interests and who may go un-noticed in larger groups (Olson, 1965). Larger groups require special instruments, devices, or regulations to ensure compliance that goes beyond the current capacity of the project (time and funds). Starting with small groups is preferred where capacity is developed and instruments that could be applied to larger groups can be created and tested. There are other projects and NGOs working with farming groups in the Pacific which will be valuable sources of information and collaboration. One group is LRD's POETCOM group that has established a network of agricultural clusters under their Participatory Guarantee Scheme (PGS) for organic growers, and they can share their Pacific expertise on developing social capital, both 'bonding' within the group and 'bridging' to various support agencies (Gittell & Vidal, 1998).

7.1.3 How research influences actions on the ground

Evidence informs and influences actions by joining the research results to the knowledge and values of the smallholder farmers. It also connects the important extension services provided by the Ministries of Agriculture with other experts and new knowledge.

Adopting a new technology or process that has shown to increase income appears as a rational economic decision for SHF. This rational approach is also supported by Governments and donors who invest in livelihood improvement. However, it is a challenge for evidential projects to get SHF adoption of incremental change and much rarer for transformational change. This suggests SHFs are either not making economically rational decisions or hold a different view of rationality. However, the Social Capital and values of SHFs are considered with their specialist knowledge of their lifestyle and dynamic environments to make decisions that are more than likely very rational.

Therefore, it takes more than economic evidence to create change. It is the values, attitudes, and behaviour of SHFs that the evidence must align for adoption to occur. In the diagram of the Project Theory of Change, the assumptions emphasise the engagement of SHFs and their willingness and capacity for collective action. This people-centric approach to develop agricultural clusters for collective action around the ‘baby’ trial sites brings together the biophysical and socio-economic evidence. Recent Climate Change adaptation programs in Indonesia show that without the engagement of SHFs there is little impact and the fostering of adaptive capacity is limited (Turner-Walker & Anantasari, 2020). The alignment of these quantitative and qualitative results will increase the possibility of influence on SHF actions and sustainable impacts.

7.2 In-country industry and community partnerships and contributions to SRA

7.2.1 Industry and Community Partnerships: Samoa

This SRA initiated new research and collaboration networks with key agricultural and community representatives in Samoa. Mr Afamasaga Toleafoa, President of the Samoa Farmers Association (SFA) and Chairman of Pacific Island Farmers Organisation Network (PIFON) donated his time and provided valuable input from the farmers' perspective. A number of initial conversations and provision of field-based information provided valuable context for the conceptualisation and planning of the project, and for choosing the targeted farming systems. Mr Toleafoa also suggested the 'first-responder' farmer contacts in Samoa for the SRA, considering differences in location, soil type and climate required in the project.

Mr Toleafoa gave constructive feedback for the SRA during the development of the questionnaires for the Samoan farming systems. This included the appropriate use of customary terminology, background information on customary titles, typical farming parameters and practices, farming family- and gender-related practices, climate change-related topics, as well as on the various practical challenges faced by Samoan farmers. Mr Toleafoa also gave unique depth of insight of the wider issues in Samoan agriculture in the past 10 years, including commercialisation, technological innovation, training and development, government investment and international development. His outstanding contribution to the SRA is gratefully acknowledged by the project team.

> The proposed sustainable intensification in agriculture project is a very topical and relevant subject today after the COVID-19 pandemic reminder about food security and food dependence in the Pacific.
>
> AFAMASAGA TOLEAFOA,
>
> President of the Samoa Farmers Association, and Chairman of the Pacific Island Farmers Organisation Network (PIFON), 2020

We would like to mention in particular two other members of the Samoan Project Advisory Group who generously volunteered their time and provided additional and valuable insight from other angles related to the project. Mr Seuseu Tauati, CEO of the Scientific Research Organisation of Samoa (SROS) provided recommendations for the research part of the SRA, including farmer contacts and suggestions for research methodology. Mr Oliver Ubaub, Manager of Sunshine Farm, provided additional insights from the industry and commercialisation perspective.

Mr Seumanu Gauna Wong from the National University of Samoa (NUS) also provided valuable perspectives, and brought to the SRA additional long-established networks in MAF and SROS that became instrumental in the formation and delivery of our project. There was a united belief in the agricultural industry and communities of Samoa that promotion and support for Conservation Agriculture and Sustainable Intensification was desperately needed. We were therefore blessed with the support from other stakeholders such as Sunshine Farm owned by Frankie, one of the two major farm-to-shop/table supply chain operators, The Women in Business Network, SFA, the Informal Gardeners Group, and ordinary farmers, both women and men.

The Chief Executive of the Ministry of Agriculture and Fisheries, Mr Tilafono David Hunter was a member of our Samoa Project Advisory Group, and met with us on a number of occasions for consultations and planning. He then authorised that we could have access to and work with senior officials in Crops and Livestock Groups in MAF. Mr Seumanu Gauna Wong of the National University of Samoa connected with MAF's Director of Crops, Mr Tanu Toomata and Mr Tommy Tuuamalii, and MAF Staff at Nu'u, to organise meetings with Extension Officers in Upolu and Savaii. At the Extensions Officers meeting, we presented the CASI approach and were introduced to Mr Mu Vaamainuu and Ms Seluia Afaese from Savaii who then worked with us to conduct the surveys in Savaii and the Focus Group Discussions in Salelologa. Two of USP's recent graduates working at the MAF, Ms Tusiata Lemuelu Salu and Faatoialemanu Areta were released for a week to assist with the survey in Savaii. Mr Tommy Tuuamali and the MAF Staff at Nu'u organised the Upolu farmers Focus Group Discussions in Upolu, while Mr Mu Vaaimainuu and Ms Seluia Afaese and their colleagues in Salelologa organised the Focus Group Discussions in Savaii.

Ms Adimaimalaga Tafuna'i, the Executive Director of Women in Business gave useful advice on the types of farming and commercial activities undertaken by her Network members.

We are now working collaboratively with these partners and their networks to promote the CASI ideals. These include the many farmers, both women and men, who are now looking forward to seeing how our sustainable intensification approach can help them address some of the challenges that have weakened their performance or prevented them from accomplishing the goals that they have been striving to attain.

7.2.2 Industry and Community Partnerships: Tonga

Outstanding contributions and commitments have been made to the SRA by the leading agricultural industry and community groups in Tonga, in particular the *Mainstreaming of Rural Development Innovation Tonga Trust* (MORDI TT; https://www.morditonga.to/).

MORDI TT started as a project in 2007 and was registered as an NGO in 2009. Its purpose is to empower rural communities in Tonga to fight against poverty and attain food security. MORDI's main goal is to contribute to the improved sustainable livelihoods of vulnerable communities in rural areas in Tonga. This is achieved through the provision of skill development training and implementation of community development projects.

MORDI TT CEO Soane Patolo, and his organisation, became enthusiastically involved in this SRA from the outset. He was involved in many discussions during the formative and early stages of the CASI SRA. He "jumped' at the partnership because he was convinced in the value of CASI research and knowledge it could generate to benefit the farmers and rural communities in Tonga.

The goal of MORDI TT's program has been designed with four main components which contribute to the reduction of rural poverty by enabling rural communities to enhance their livelihood opportunities and reduce their vulnerability. The four components are (1) Community Empowerment; (2) Economic Empowerment; and (3) Learning, Sharing and Upscaling, and (4) Creation of Change and Monitoring.

A flagship of MORDI TT's operations has been the Tonga Rural Innovation Project (TRIP I) in association with IFAD that reached 60 target communities, 2,800 households, and 16,901 people. The project solely focused on community development and as such was able to deliver to the Tongan Government's 60 Community Development Plans that were endorsed.

> **C**onservation **A**griculture and **S**ustainable **I**ntensification is exactly what MORDI TT, farmers, and the rural communities have been waiting for - Research to understand farming systems and contribute to increasing productivity, soil health and reduce greenhouse gases – all are important priorities to the farmers and communities in Tonga.
>
> CASI will contribute to sustainable, improved livelihoods of vulnerable communities, especially women and youth, living in the rural areas of Tonga, in line with the Millennium Development Goals
>
> SOANE PATOLO, CEO MORDI TT 2020

TRIP II began in 2018 and has doubled its target communities reaching 122 rural communities, 7,300 households, 39,300 people. TRIP II has two components: (1) Community Development, (2) Sustainable Economic Livelihoods.

MORDI TT's work now covers all rural communities and population of Tonga. MORDI TT partners with the Ministry of Internal Affairs, Ministry of Finance, Ministry of Agriculture, Food and Forestry and many farmers (commercial, semi-commercial, and subsistence) and the private sector. MORDI TT's current activities include:

- Farmer to farmer exchange
- Homestead gardens for women's groups
- Reviving traditional fishing methods
- Male at-risk youths to explore possible livelihoods in agriculture and rural development
- Trialling new crops, varieties and farming systems.

In July 2021, His Royal Highness the King of Tonga granted MORDI TT access to 30 acres of land on the 'Api Fatai Royal Estate for agricultural development projects including for Conservation Agriculture Sustainable Intensification work to follow the SRA.

The agricultural industries and communities of Tonga were the heart of the CASI SRA Project Advisory Group, and provided unparalleled support to the project, including as outlined in Section 5 of this report *Methodology.* Also see Section 7.2.3 for the make-up and operations of the Tonga Project Advisory Group. A few extra comments are made now recognising the support of the Tonga agriculture industry and community to the SRA through the Project Advisory Group.

The University of the South Pacific campus in Tonga was represented on the PAG by the Campus Director, Dr Robin Havea. He was the chairman of the PAG chosen by the members. The involvement of the Tonga Campus was important to ensure future engagement of students, researchers and staff from the USP campus to the CASI full project.

Ministry of Agriculture, Food and Forests (MAFF) http://mafff.gov.to/ is the main government arm responsible for agriculture research, extension services and agricultural value adding in Tonga. The representative from MAFF to the PAG was Mr Elisaia Ika, who is the Head of Research Division in Tonga.

There were two representatives of the agricultural industry and farmers (mainly commercial farmers) in the PAG:

One was Mr Minoru Nishi Jr - a commercial farmer and Managing Director for Nishi Trading Ltd, a family-owned food and agricultural farming, processing and export company (http://www.nishitrading.com/). Nishi Trading Ltd have been the core partner of Value Chain Assessments in Tonga. Mr Nishi is also board member of the Pacific Islands Farmers Organization Network (PIFON), a network of 23 farmers organisations, supporting 80,000 farmers in nine Pacific Island Countries. He is also a member of the Tonga Growth Committee. Mr Nishi also brought the networks of PIFON and the Tonga Growth Committee to the PAG.

The other representative of the agricultural industry and farmers was Ms Melesisi Finefeuiaki of the Loto Poha Organisation, a highly successful multi-level agricultural company in Tonga.

The community was represented by Mr Soane Patolo, the CEO for Mainstreaming of Rural Development and Innovation, Tonga Trust (MORDI TT), an NGO that focuses on sustainable livelihood of rural communities in Tonga, as mentioned above.

Technical experts were represented by Dr Siosiua Halavatau who is a soil scientist and an expert of farming systems in Tonga and the Pacific Islands. He was a Deputy Director for the Land Resources Division, Pacific Community for many years.

7.2.3 Project Advisory Groups: Samoa and Tonga

Separate Project Advisory Groups (PAG) were formed for Samoa and Tonga. These Groups were made up of prominent leaders in agriculture, land systems, and food - including farmers, farmer groups, government officials, industry stakeholders, educators, and research institutions (See below for memberships of the PAGs).

The PAGs provided guidance, oversight, and direction to help steer the project. They also assisted with project implementation, and facilitated broader community engagement and involvement with the project. The PAGs were the gateway to genuine collaboration with stakeholders. The project team ensured gender balance in the PAGs as much as possible.

Members of the PAGs and their networks were a major force in delivering the survey components of the SRA.

1. Agreed Terms of Reference for the Project Advisory Groups

Terms of Reference as agreed by both PAGs are as follows:

1. Provide well-informed, 'on-the-ground' strategic advice to the Project Team from the perspective of (1) industry and farmers, (2) research and education providers, (3) government, and (4) communities.
2. Advise on opportunities for the Project Team to utilise networks and wide-ranging expertise to engage effectively and constructively with (1) industry and farmers, (2) research and education providers, (3) government, and (4) communities.
3. Meet regularly (at least twice a year) and provide diverse opinions to the Project Team on opportunities to maximise the value of project delivery, outputs, and adoption of *Sustainable Intensification* for multiple benefit.
4. Advise on the scope and development of a new *Sustainable Intensification* project(s) to follow, including opportunities for funding and partnerships.
5. Facilitate timely access to research permits and data.

2. Project Advisory Groups Workshops

Major PAG workshops were held in both Samoa and Tonga in December 2021. These workshops were enormously valuable forums for the project team to receive input and advice from the PAGs.

Highlights from these workshops were:

1. ***Shared understanding of aims and approaches to be taken in the SRA, and input received from the PAGs on project design and methodologies.***
    - Project lead, Prof Tim Reeves presented the key components of the ACIAR SRA, and the proposed approaches to be used to test possible CASI interventions in Samoa and Tonga. Constructive input and advice were received from the PAGs.

2. ***Agreed Terms of Reference and Roles of the PAGs***
   - Project team member Associate Prof David Ugalde led discussion on the possible roles of the PAGs, and constructive input and advice was received. The PAGs agreed to Terms of Reference, and agreed on their operations.

3. ***Agreement on Continuing Roles of PAGs in the SRA and the Full Project to Follow***
   - PAGs proposed that their roles would not stop when the SRA was completed, and wished to continue to provide input and advice to formulating and delivering any further work to follow - including a possible full proposal through ACIAR.
   - Indeed, the PAGs provided explicit recommendations that this CASI work needs to continue beyond the SRA, and have offered their services in any work to follow. They expressed a wish to be able to provide advice on the highest priorities, and to be able to contribute to maximising the value of CASI to farming systems, farmers, food systems, and societies in the target areas. There is an urgent need to provide more nutritious food in the Pacific Islands.

4. ***Agreement on Farming Systems of the SRA***
   - At the Samoa PAG workshop, project team member Dr Joeli Veitayaki presented and explained the two farming systems proposed for the study in Samoa. Dr Veitayaki also highlighted the contemporary challenges for Pacific Island Countries such as: Food Security (ensuring we have enough healthy nutritious food for ourselves), Sustainability (ensuring that the agriculture systems are productive over time) and Climate Change Resilience (agriculture systems adapted to changing climatic conditions). The farming systems for the Samoa component of the project was agreed.
   - At the Tonga PAG workshop, project team member Dr Viliamu Iese presented and explained the two farming systems proposed for the study in Tonga. The farming systems for the Tonga component of the project was agreed.

5. ***Agreement on Survey Design, Questionnaires, and Obtaining Responses***
   - Team member Dr Gayathri Mekala presented an overview of the purpose of the survey, the design of the questionnaire, and explored options for the best way to conduct the interviews. This presentation also drew out the gender components of the survey, and the requirements for ethics approval. The survey is a highly valuable component of the SRA, as shown in this Final Report.
   - The project team received fantastic input from the PAGs to the design and delivery of the surveys. This input continued to the finalisation of the questionnaires. The PAGs were then instrumental in the successful conduct (data collection) and completion of the surveys. The project team wish to acknowledge this input from the PAGs to the project surveys, and to thank the PAGs most sincerely for their contributions to the surveys.

3. Members of Samoa Project Advisory Group

Government Representative	
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4. Members of Tonga Project Advisory Group

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Melesisi Finefeuiaki (F)	Loto Poha Organisation; msfinefeuiaki@gmail.com
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7.3 Implications of CASI for Integrated Crop-Livestock Farming Systems in Samoa

This section (Section 7.3) describes the integrated crop-livestock systems in Samoa, and the potential of CASI to impart a range of broad-based production benefits to these farming systems, and financial and social benefits to the farmers and their families using these systems.

The information has been provided by members of the Samoa Project Advisory Committee, their networks, industry focus group discussions at the Agriculture stations in Nuu in Upolu, and at Salelologa in Savaii, and an extensive survey of farmers and their families in Samoa who farm using integrated crop-livestock farming systems. This information was supplemented by government and industry publications.

The methodology for the survey is in Section 5. The questionnaire for the survey of farmers and their families for the integrated crop-livestock systems in Samoa is available in the Supplementary Information Section 12.1.

Extensive details of the range of crops grown, and the techniques of crop management used in the integrated crop-livestock farming systems in Samoa – as studied in this SRA - are not presented in full in this Final Report. Only summary information and key conclusions are provided here. Full details are being prepared for publication.

7.3.1 Description of targeted farming systems: Integrated Crop-Livestock Systems in Samoa

There are two basic forms of integrated crop-livestock farming systems in Samoa. First, there are systems where the production of both crops and livestock overlap within the same farming space in some form of rotational or integrated system. Secondly, there are systems where crops and livestock occur essentially side-by-side or in parallel in different farming spaces on the one farm with operations, labour, resources and finances integrated. Both types of integrated farming systems were considered in this ACIAR study.

The size of the land holding of an integrated crop-livestock farm in Samoa is usually in the range of two to eight acres. Eighty percent (80%) of the people are landowners who hold 80% of land in Samoa under customary titles (land titles passed on within the family and retained within the group). There are obligations, referred to a *tautua* in local language and expectations within these family lines to maintain farming on the inherited lands.

Traditionally, integrated crop-livestock farming systems have been classified (or seen by these farmers) as *semi-subsistence.* However, over the past 10 years or so, there have been increasing investments by commercial farmers, international organisations, and the Samoan government into these farming systems. As a result, the integrated crop-livestock farming systems in Samoa have become more commercialised, seen the introduction of new technologies, witnessed the development of new skills and trainings, and observed the formation of specific integrated crop-livestock farmer organisations.

Travel is also more common now (Covid-19 restrictions notwithstanding), and families or individuals who travel abroad or even migrate permanently to other countries also re-invest back into Samoan agriculture, often bringing back new technologies to be used in the integrated crop-livestock farming systems.

A couple of simple examples of new technologies that are becoming more commonplace in the Samoan integrated crop-livestock farming systems are biodigesters to produce gas for domestic and farming operations from animal waste, and re-use of animal slurry and waste as bio-fertilisers.

Main crops, varieties, and cultivars

There is a wide variety of crops grown in the integrated crop-livestock farming systems of Samoa - with the main ones being taro, yams, cassava, giant taro, cocoa, bananas, fruit trees, native trees for timber.

Vegetable seeds are expensive and in short supply. Occasionally, new improved varieties of crops become available for farmers to try, but generally the use of traditional varieties persists. A new banana variety has recently been imported from Israel but is only mostly cropped by large holders and requires higher levels of maintenance costs – these additional costs are of particular concern for the smaller operators where there are not the advantages of scale. Medium to small banana growers still plant the local varieties.

Livestock

Cattle and chicken are most common. Some farmers also have sheep and pigs. Cattle mostly graze pastures; chickens free range; pigs mostly free range, although some are raised in barns with feed provided.

Labour

There is a clear demarcation in the activities done by women and men on integrated crop-livestock farms. Managing tree crops, pruning, planting taro and other physically taxing activities are generally done by men. Planting of vegetables, weeding and processing are generally done by women. The pay is similar for all kinds of activities unless it is a specialised activity like heavy and delicate cutting and clearing of trees. Children also help in agriculture and support farming operations like doing chores, running errands, bringing food and water for the farm workers. The division of labour and implications of CASI for gender are analysed and presented more fully in Section 7.3.2.

Soil management

Large-scale tillage is not common in the integrated crop-livestock farming systems of Samoa, due mainly to the dominant rocky soils. Rotovator tillage is used by some of the larger vegetable farmers, who have removed the rocks within the farmed areas. Taro farmers mainly use the ‘oso’ or digging stick.

Rotations and use of fallow

Fallow is often a part of the sheep and taro integration mainly as a management tool to control weeds. In some cases, animals and cropping are in a rotation on the same parcel of land.

Nutrition

The re-introduction of livestock manure to the soil is a common practice to improve soil fertility for this system. Additionally, synthetic fertilisers like NPK and urea are used for vegetables. Mulching, compost, crop rotation and intercropping are used as a nutritional management measure. A more scientific approach to managing soil nutrition, which requires soil testing and determining the nutrients that are required by the particular crops, is constantly requested by farmers.

Nutrients can be recycled, which accelerates nutrient turnover within the system. Recycling also improves efficiency of production with optimal use of resources needing to be matched with the farming objectives. This includes externalities such as environmental impacts, food security and land tenure.

Water management

There are very few reticulated irrigation water systems in Samoa. Main sources of water for production are rain and tap water, which makes drought a major threat. Rainwater may be harvested and stored on farm, and then applied to livestock and vegetables as required. Tap water is often relied upon for livestock and vegetables.

Weed control

There is a wide range of weeds and there is the constant need for control measures. Invasive species such as African tulip (*Spathodea campanulata*), tamalini (*Paraserianthes falcataria*) and rubber (*Hevea brasiliensis*) worsen the challenge given their aggressive and dominating nature. Most common control is still non-chemical – removing plants.

Pest and disease control

There is minimal pest control for livestock. Parasitic worms are normally controlled by drenching and rotational grazing.

Vegetables are normally grown during the cool and dry season when pest infestations are low. The cabbage moth is the main pest of brassicas and is controlled by pesticides such as *Attack.*

There is a wide range of common plant diseases. The most common control is constant vigilance to remove infected plants or parts of plants. No chemical control for common plant disease was reported in our study.

Products and marketing

A frequent production problem for the livestock is feed shortage and cost if it needs to be sourced externally from the farm.

An overriding problem is the customary obligation of sharing the produce amongst family and local communities - called *tautua*. Most integrated crop-livestock farmers recognise the need to produce enough farm product for family food, sale, loss due to theft, religious and traditional obligations.

As much of the marketing is local, there are few recognised marketing problems. More recently, and during COVID 19 lockdowns, there has been an increasing use of online marketing.

Climate change impacts on production

Seasonal fluctuations in weather and climate are now more difficult to predict, presenting additional challenges for most integrated crop-livestock farmers to match production with market demands. It is recognised that climate change is increasingly impacting the whole production cycle and production scheduling.

Potential for change and adopting CASI interventions

From our study, most integrated crop-livestock farmers in Samoa felt that they would adopt CASI interventions because of the increasing vulnerability and challenges of agriculture due to climate change and the increasing pressures on farmers to maintain production.

This was based on a very general discussion of CASI interventions and their potential benefits, but it at least shows that farmers have a willingness to explore and trial CASI interventions to better understand the specific balance of benefits and costs.

7.3.2 Social and gender factors impacting on Integrated Crop-Livestock Systems in Samoa, and implications for CASI

Extensive surveys were conducted of farmers and their families in Samoa using integrated crop-livestock farming systems. The methodology for the survey is in Section 5. The questionnaire for the survey is in the Supplementary Information Section 12.1.

A major part of this survey focussed on social and gender factors related to both on-farm and off-farm operations of these farming systems, and on the implications for the introduction of CASI in these systems. Men and women were interviewed separately to explore whether there may be different perceptions of the breakdown of roles and responsibilities.

Only a snapshot of the results concerning social and gender factors obtained in this survey is presented here. Full details are being prepared for publication.

Overall, the survey found that currently there is a trend towards females having increasing roles in the production and marketing of the farm produce in the integrated crop-livestock farming systems in Samoa. An organisation called the *Samoa Women's Association of Growers* has been formed and many women involved in the farming operations in Samoa are active members of this Association.

Part 1. Roles and Responsibilities of Men and Women in the Cropping Phase of the Integrated Crop-Livestock Farming Systems in Samoa

Crop Production

Key points:

- Men and women about equally share roles and responsibilities for farm planning, and for environmental and conservation management.
- Men are predominantly responsible for delivering the manual on-farm operations, i.e. predominantly responsible for:
    1. Soil preparation before planting
    2. Planting
    3. Application of farm chemicals (fertilisers, herbicides, pesticides)
    4. Irrigation and water management
    5. Weeding
    6. Harvesting
    7. Storage of the harvested crop
    8. Maintenance and repair of machinery, equipment, and fencing.
- While men are predominantly responsible for these manual on-farm operations, women assist with delivering manual on-farm tasks as well – usually delivering about half the input to the on-farm manual tasks in the cropping phase as men deliver (i.e. about one-third the total manual workload required).
- Children are rarely involved in farm planning, and in environmental and conservation management. They do help out from an early age with the manual tasks on farm. Their contribution is well valued. Generally, around 15% of the work effort required for the manual tasks on-farm related to the cropping phase particularly watering, weeding, and harvesting is delivered by children.

- ***Crop Marketing***

Key points:

- Both men and women play about equal roles in sales planning and/or contracting.
- Men are predominantly responsible for (1) preparing the produce for sale, (2) packing shed operations, and (3) transport of the produce to the market or depot.
- Both men and women play equal roles in selling.
- Women are predominantly responsible for receiving and handling of monies.
- Children contribute well to (1) the preparation of the produce for sale, (2) packing shed operations, and (3) selling the produce at market.

Part 2. Roles and Responsibilities of Men and Women in the Livestock Phase of the Integrated Crop-Livestock Farming Systems in Samoa

Livestock production

Key points:

- In contrast to the even distribution of work roles in on-farm operations in the cropping phase of the integrated crop-livestock farming systems, men are almost entirely responsible for the on-farm operations for livestock production, which covers:
  1. Farm production planning
  2. Environmental and conservation management
  3. Production of fodder
  4. Watering the animals
  5. Milking (if applicable)
  6. Routine animal health and husbandry
  7. Care of young animals
  8. Care of sick animals
  9. Shed/pen cleaning.
- Children contribute in (1) watering the animals, and (2) shed/pen cleaning.

Livestock marketing

Key points:

- In contrast to the dominance of men in the on-farm livestock production), there are about equal responsibilities and work-effort between men and women in (1) sales planning and contracting, and (2) selling animals.
- Men predominately deliver the tasks of (1) processing the animals for sale, (2) licencing and regulation requirements.
- Women predominantly receive and manage monies.

Part 3. Access to and Control of Resources by Men and Women in Integrated Crop-Livestock Farming Systems in Samoa

Key points:

- Most men in Samoa live and serve (tautua) in the wife's family. Hence, females have good access to, and control of, resources generally.
- Women farm owners have particularly good access to, and control of, the resources of their farm.
- In farms owned by man, women are generally well consulted and share access to and control of resources.
- Gender equality is now being strongly practiced on integrated crop-livestock farms in Samoa, as indeed it is in Samoan society generally.
- Our analysis examined access to and control of a number of defined farm parameters between men and women in integrated crop-livestock systems. These were:
    1. Land
    2. Crops
    3. Livestock
    4. Credit
    5. Labour
    6. Agricultural information.

  We could not find any substantial difference between men and women in the accessing or controlling of these parameters.
- In examining the distribution of benefits from the farming operations in the integrated crop-livestock systems we could not find any substantial difference between men and women.

Part 4. Information on Production and Marketing Operations, Sources of this Information, and Access to this Information by Men and Women

Key points:

- There are a wide variety of sources of production and marketing information for farmers of the integrated crop-livestock farming systems in Samoa. This covers:
    1. Advice from the Ministry of Agriculture and Fisheries
    2. Other farmers
    3. Family and friends from both within Samoa and overseas
    4. The media – in particular radio and TV
    5. The internet.
- Farmers recognise that the different sources of information contribute differently to the type of information required. There are differences in the reliability of the information depending on the source. The Ministry of Agriculture and Fisheries was particularly strong and reliable for formal training and training manuals. Industry sources were particularly strong and reliable for specific and targeted information requests.
- Both men and women in the integrated crop-livestock farms in Samoa farms felt that they had equal access to the available information, and both equally expressed views on the reliability of the information.
- There were only two major concerns regarding the transfer of information expressed by integrated crop-livestock farmers in Samoa, and this was viewed equally by both men and women:

1. There are sometimes gaps in the information especially relating to the latest innovation in farming and marketing practices.
2. There are sometimes lags in information becoming available especially relating to transfer of information from research into a form that can be used by farmers.

- Integrated crop-livestock farmers in Samoa felt that the available channels of information are already in place, and would greatly assist in the implementation of any new farming practices such as CASI.

Part 5. Access to Key Agricultural Inputs and Support Services

Key points:

- Our study examined access to key agricultural inputs and support services under the following assessment criteria:
    1. Not available
    2. Available in limited quantity
    3. Available but poor quality
    4. Available but not timely
    5. Available but expensive
    6. Available but have to travel far
    7. Readily available.
- We were provided information on the following agricultural inputs and support services:
    1. Seed
    2. Fertilisers
    3. Chemical inputs
    4. Labour
    5. Soil testing
    6. Information on machinery
    7. Purchasing of machinery
    8. Advice on the use of machinery
    9. Servicing of machinery
    10. Repairs of machinery
    11. Resale of machinery.
- The general responses were that many of the agricultural inputs and support services required by integrated crop-livestock farmers in Samoa were mostly *Not Available*. In addition, if any of these inputs were indeed available, they were expensive.
- Generally, there were very few differences in the way that man and women viewed access to the agricultural inputs and support services.
- There were three stand-outs or exceptions to these generalised responses outlined above:
    1. There was good access to required labour

2. Soil testing was rarely available under any of the conditions of supply, and this severely hindered the ability to make good management decisions concerning nutrition
3. There were substantial differences between the responses of men and women in accessing all support services relating to machinery. There was a much greater response from men that the required services for machinery was critically not available.

Part 6. Take-Home Messages and Implications for CASI

- We could find no major disparities between gender in the integrated crop-livestock farming systems in Samoa that may hinder or adversely impact on the application of CASI to these farming systems, or to the implementation of CASI into management and decision-making both on-farm, and in product marketing.
- We could not find any social, structural, policy, or institutional barriers to implementation of CASI in these farming systems.
- Benefits of CASI would be shared equally between genders, and indeed equally within families and within the societal family structures.
- The analysis of access to key agricultural inputs and support services provided some keen insights into the challenges for implementing CASI. First, farmers recognised that there was very limited access to all support services for machinery required to improve soil management, and secondly support services for soil analysis were virtually non-existent as required to improve plant nutrition.

7.3.3 Strengths, Weaknesses, Opportunities and Threats of the existing Integrated Crop-Livestock Systems in Samoa, and implications for CASI

The SWOT analysis of the Integrated Crop-Livestock Farming Systems in Samoa, as outlined in the following table, was undertaken primarily by Samoan farmers, industry representatives, government personnel, and members of the Samoa Project Advisory Committee during the facilitated focus group discussions. The SWOT was complimented by secondary information sourced from published reports, journal articles, books, and unpublished data.

Strengths, Weaknesses, Opportunities and Threats of the Existing Integrated Crop-Livestock Systems in Samoa
1. STRENGTHS BIOPHYSICAL • Nutrients recycled on farm and optimal use of resources. • Sheep do not eat taro while helping control weed and add nutrients to the soil. • Chicken raised with green pepper, yams, turmeric, banana and flowers provide multiple complimentary benefits and diverse income source. • Raising cattle in coconut or cocoa plantation ensure multiple sources of income, maintain healthy environment that is beneficial to animals and the trees. • Integrated crop and livestock farming requires minimum tillage and is rain-fed.

SOCIAL, INSTITUTIONAL AND GENDER

- Integrated farming supports farmers' social and cultural obligations.
- Families abroad invest in farming while some of them bring back new technologies.
- Samoan Ministry of Agriculture and Fisheries supports integrated agriculture.

2. WEAKNESSES

BIOPHYSICAL

- Samoa has limited arable land for agriculture production.
- Integrated crop and livestock farming change biodiversity through selectivity.
- Overgrazing results in poorer soil structure, erosion, compaction & degradation.
- Long fallows in sheep and taro integration to control weeds.

SOCIAL, INSTITUTIONAL AND GENDER

- Poor record keeping; High cost of feed; Poor waste management causes pollution; Shortage of fences, sheds, livestock, feed, water; Fertilisers are not widely used, which affect the health of soil; Herbicides are used for controlling vegetation.
- Technical support is inadequate; Paddock size affects rotational grazing.
- Limited infrastructure resulting in bush slaughtering and culling.
- Traditional governance and cultural systems create challenges to gender equality because of their focus on the rights of groups over the rights of individuals.

3. OPPORTUNITIES

BIOPHYSICAL

- Given the vulnerability of land due to geography and climate change, farmers will adopt CASI interventions provided it is linked to income, food, culture, and religious obligations.
- Mulching, compost, crop rotation and intercropping is used but farmers request a more scientific approach.
- Soil testing and determination of what nutrients the soils require.
- Vegetables are grown during the cool and dry season when pest infestation are low.
- Process waste to reduce costs and better use the resources for cleaner environment.

SOCIAL, INSTITUTIONAL AND GENDER

- Eighty per cent of land in Samoa is under customary titles of families and is retained within the group. This may encourage long-term investments in land improvement.
- Advisory, outreach and extension services are well supported by the MAF.
- Farmers have access to information and advice from MAF, other farmers and the media like TV and radio. Farmers also use face-book and the internet.

4. THREATS

BIOPHYSICAL

- Irregular rainfall, long dry spells and frequent floods disrupt farming schedule and stimulate growth of pests (insect pest, invasive species, weeds, feral pigs) and diseases causing losses.
- Intensive farming eventually leads to poor soil fertility.
- Poor waste management. Livestock farming increases urea concentration, which disturbs the nutrient balance.
- Water availability is a major challenge.
- Shorter fallow period threatens soil fertility, which reduces productivity.

SOCIAL, INSTITUTIONAL AND GENDER

- Capital is limited and a major constraint that limits what farmers want to do.
- Markets are unstable, oversupply of taro and meat prices are low, competition from imported alternatives.
- Land tenure issues restrict farming options/choices.
- Labour costs are high while labourers are unreliable and unskilled.
- Farmers lack technical knowledge and skills.
- Increasing use of synthetic chemicals affect soil health and increase costs.
- Integrated farming causes alteration of biodiversity and local conditions.
- Smallholder farmers do bush slaughter, which is a health risk.

7.3.4 Proposed CASI interventions for the Integrated Crop-Livestock Systems in Samoa

The group representing the Integrated Crop-Livestock Systems in Samoa who undertook the SWOT analysis (Section 7.3.3, above) then considered possible CASI interventions that may beneficially contribute to production, environmental management, financial returns, gender issues, or social well-being.

This group was made up of key representatives of farmers and their families practicing the Integrated Crop-Livestock Systems in Samoa, industry representatives, government personnel, and members of the Samoa Project Advisory Committee. Their views were sought and captured in facilitated focus group discussions. The outcome of this analysis is in the table below.

Possible CASI Interventions for Beneficial Change in the Integrated Crop-Livestock Systems in Samoa	
CURRENT CHALLENGES	**POTENTIAL CASI INTERVENTIONS**
Climate change and natural hazards Samoa experiences natural hazards regularly, particularly tropical cyclones, floods and drought.	CASI interventions could help to improve the resilience of agricultural industries to cyclones and other climate and natural hazards, and particularly could help the

	agricultural sector to recover after experiencing a cyclone, flood, or drought event. CASI could introduce different varieties of crops and breeds of livestock that are more suited to the natural conditions of Samoa, and could assist with recovery after a cyclone, flood or drought.
Declining soil productivity Agriculture in Samoa recorded negative growth rate of 0.9 contribution to GDP in 2014 and crop production decreased from 1,200 to 800 g /capita/day between 1980 and 2016. For reference see Iese et al. 2020, and Davila and Wilkes 2020. Productivity and sustainability of many cropping systems are threatened by a decline in soil fertility, soil structure and biological health of soils For reference see Davila and Wilkes 2020.	CASI could develop and illustrate nutrient recycling through different integrated crop and livestock farming system The following changes were also suggested: • Replacement of cropping systems that are unsustainable and lacking diversity, • Introduction of different types of livestock, • Increased use of legumes in crop rotations to lessen the use of N fertiliser and increase soil C and soil N levels, • Promote and support more genetic research into crops and forages to have increased water-use efficiency, be more competitive with weeds, and be more resistant to diseases.
Poor technical knowledge of handling meat and waste management from crops and livestock Challenges in management and recycling of waste include: • Poor record keeping making management decisions difficult, • Expensive cost of animal feed when alternatives could be sourced from cropping on the farm, • Poor waste management causes pollution, • Shortage of fences, sheds, livestock, feed, water to better integrate cropping and livestock, • Fertilisers are not widely used which leads to declining health of soil, • Herbicides are used for controlling vegetation – expensive and affects the environment,	Solutions through CASI could: • Provide technical advice in the setting up of a proper abattoir in Samoa where all slaughtering is done according to required health standards, and waste could be better managed, • Allow people to have quality meat from a clean environment and certified safe by qualified meat inspectors, • Present a centralised abattoir that enable people to make wise use of the blood and offal from the slaughter and allow setting up of a byproduct processing plant that will create more employment opportunities and at the same time reduce emissions to the environment, and provide organic fertilisers,

• Integrated crop-livestock farming causes alteration of biodiversity and local conditions • Smallholder farmers do bush slaughter, which is a health risk..	• Demonstrate healthier and optimal crop and livestock integration, • Illustrate zero waste closed cycle
Gender concerns in agriculture • Women in Samoa are actively engaged in subsistence farming, marketing of produce and production of value-added goods. Forty percent of women working in subsistence agriculture are below the Basic Needs Poverty Line, • Nationally, 12.8% female-headed households are below the BNPL compared to 10.1% of male-headed households, reflecting increased vulnerability for female-headed households, For reference see Moustafa 2016. • Gender Policy not being effectively utilised – There is a general lack of understanding among the staff within the Ministry (MWCSD) of key concepts of gender mainstreaming and what needs to be done at different levels to promote gender equity. Need training and capacity building for ministerial staff recognised at the higher levels of the government.	Solutions through CASI could be: • Collate and promote profiles of women farming and businesses. • Offer training and technical support based on current needs and skills assessment.

Based on the current challenges identified in Samoa for Integrated Crop-Livestock Systems, potential CASI interventions that can mitigate/address these challenges include –

- Identification and introduction of best genetic materials (drought tolerant, higher crop vigor and disease resistant) comprising different crop varieties and livestock breeds that are more suited to the natural conditions and changing climate of Samoa.
- Develop and illustrate nutrient recycling through different integrated crop and livestock farming systems including legumes in crop rotations to minimize
- synthetic nitrogen fertiliser use and to build soil carbon and nitrogen levels.
- Training program for setting up an abattoir to maintain health and hygiene
- standards, and better management of waste for a circular economy.
- Collate and promote profiles of women farming and businesses and offer training and technical support based on current needs and skills assessment.

Best possible synergetic CASI interventions and their combinations which can be validated under field conditions include: Best genetic materials (crops and livestock) being tested with nutrient cycling to minimise reliance on synthetic inputs and improved soil health.

7.4 Implications of CASI for Taro-Based Root Crop Farming Systems in Samoa

This section (Section 7.4) describes the taro-based root crop farming systems in Samoa, and the potential of CASI to impart a range of broad-based production benefits to these farming systems, and financial and social benefits to the farmers and their families using these systems.

The information was provided by members of the Samoa Project Advisory Committee, their networks, industry focus group discussions at the Samoa Campus of USP, and an extensive survey of farmers and their families using taro-based root crop farming systems in Samoa. This information was supplemented by government and industry publications.

The methodology for the survey is in Section 5. The questionnaire for the survey of farmers and their families involved in taro-based root crop farming systems in Samoa is available in Supplementary Information Section 12.2.

Extensive details of the range of crops grown and the techniques of crop management used in taro-based root crop farming systems in Samoa – as obtained in this SRA - are not presented in full in this Final Report. Only summary information and key conclusions are provided here. Full details are being prepared for publication.

7.4.1 Description of targeted farming systems: Taro-Based Root Crop Farming Systems in Samoa

Taro (*Colocasia esculenta*) is the main staple and primary cash crop in Samoa (MAFFM, 2015). It is grown in mixed cropping systems, often under coconut trees, and also extensively as a monocrop, in areas where forests and abandoned bush land were cleared for planting. In addition to its value as a cash crop, taro has significant cultural and dietary importance in Samoa.

Taro is also intercropped with yam, pineapple, alocasia, bananas or cassava. It is also sometimes grown in between rows of tree crops such as coconuts.

Taro-based root crop farming systems are steeped in tradition in the form of semi-subsistence farming. However, over the past few decades a commercial approach in this farming system has become more prominent. The taro-based root crop farming system is strongly supported in Samoa for providing food security, alternative income sources, employment, and development of rural regions.

The size of the land holding of a taro-based root crop farming system in Samoa (as with other traditionally-based farming systems) is usually in the range of two to eight acres. Eighty percent (80%) of Samoans own the land they use for farming under customary titles. There are obligations and expectations within family lines to maintain farming on the inherited lands (referred to as *tautua*).

Main crops, varieties, and cultivars:

Taro production in Samoa is traditionally based on four main varieties: Taro Manu'a (Purplish white), Taro Niue (Pink type), Taro Pa'epa'e (Whitish type), and Taro Palagi (Xanthosoma).

Taro Niue has not been grown widely since the taro leaf blight epidemic of 1993 as this variety is recognised as being more susceptible to blight than other varieties.

New varieties such as Talo Tanu, Talo Fusi and Talo Lani are selections of Taro Niue derived from strains discovered in the Tanumalala, Fusi and Salani villages that were observed in the field to be more resistant to blight. They were tested and released by SPC in 2015, and are satisfying the taro export industry demand for pink taro in New Zealand and further afield. Other varieties such as Famasina and Polovoli that are more resistant to blight are now available and commonly grown.

All taro farmers are now planting the new and improved varieties released after the taro leaf blight infestation. Each farmer has one, two, or possibly three preferred varieties that are known through experience to grow well on their farm, and known to satisfy requirements for export.

Labour

As with other farming systems in Samoa, there is a clear demarcation in the activities done by women and men in taro-based root crop farms. Activities such as managing tree crops, pruning, planting taro and other physically taxing activities are generally done by men. Planting of vegetables, weeding and processing are generally done by women. Children also help with farming operations. The division of labour and implications of CASI for gender are analysed and presented more fully in Section 7.3.2.

Soil management

As with other farming systems in Samoa, extensive soil cultivation is not common in the taro-based root crop farming system. Some rotary hoeing is used occasionally, but more commonly minimum tillage is used – with spot turn-over of soil by hand with the ‘oso’ - the metal digging stick.

Rotations and use of fallow

Fallowing is common. It is seen as a way to maintain soil fertility and to allow the soil to ‘recover’ for the next crop. Up to one year fallow often follows each taro crop.

Even though fallowing is customary, recent trends have shown the fallow periods becoming shorter, or even in some cases ignored because of the aspiration to maximise the return from the farms. Farmers are also reporting increasing use of chemicals to compensate for shorter fallows.

Nutrition

Taro farmers rarely use inorganic fertilisers. Generally, they only use mulch and fallowing to improve soil fertility. All plant material is left on the field during the preparation of the land for planting and after weeding.

Occasionally, one dose of urea is applied right at the start of the crop and maybe one NPK top-up dose at a later stage for taro. Inorganic fertilisers are not used by many farmers, but if they are, they are rarely measured and maybe are used at the rate of one handful per plant. Some farmers also reported occasionally using animal manure – mainly from poultry.

Water management

Taro is not irrigated and is totally dependent on incident rain. This is the same for other staple crops like banana, yams and ta'amu. Vegetables are irrigated with tap or harvested water from time-to time to supplement water from rain.

Weed control

Weedicides are widely used when land is first cleared and at the end of a fallow period. Once the crop is planted, herbicides are used only sparingly (two to three times a year). Manual weeding is still the dominant form of weed control during the growing seasons.

Pest and disease control

Pests in taro are minimal with the new varieties (see above varietal resistance to leaf blight). Varietal resistance is increasingly becoming more effective with other staples like banana, breadfruit, yam and alocasia. The crops are well tendered, and there is usually a quick response to removing affected plants or parts of plants (usually leaves). Chemical control of pests and disease is rare.

With vegetables, cluster caterpillar *Spodoptera litura* remains a serious pest. This is the one pest where chemical control is used - with Orthene, Xtra, or Attack. Corm rot by *Pythium spp*. remains a considerable problem especially with yams in excessively wet areas. The control for corm rot is to use heathy planting material, improve drainage and/or remove affected plants.

Products and marketing

Taro and other crops are sold largely in local markets, market outlets, and online. The prices obtained locally fluctuate dependent on the balance of supply and demand at the time. There are also increasing exports of taro, especially to New Zealand, although farmers are of the view that there is much greater potential for export than is currently being developed. It is generally accepted that marketing of taro does not have many difficulties, although opportunities for expansion still remain.

There may be considerable loss of taro due to feral pigs. This is usually addressed by keeping dogs on the farm, and culling.

The taro leaf blight caused by the fungus *Phytophthora colocasia* decimated the taro crop in the mid-1990s. Production of taro has increased substantially since then with the use of TLB-resistant varieties.

There are concerns that higher taro production will reduce (and is already reducing) soil health. There is a view among many farmers that greater emphasis should be placed on sustainable agriculture practices – returning to the more traditional farming methods to arrest the degradation of natural resources even if this means some sacrifice to short-term yields and production.

Sources and gaps in information

Farmers using taro-based root crop farming systems still rely mainly on the access to information and advice from the Ministry of Agriculture and Fisheries, Samoa, as has been commonplace over many decades. There is, however, increasing use of electronic (TV, radio), internet web sites, and social media (e.g. Facebook). Farmers are generally of the view that there is too much of a lag between the generation of new knowledge and the information being available to them to guide them in decision-making and adoption of new innovations.

Most taro farmers work on their own, relatively isolated from structured or formal cluster groups or information-exchange networks. They tend to rely more so on casual communications with fellow farmers through village and district meetings and/or village/family working groups.

Climate change impacts on production

Farmers of taro-based root crop farming systems recognise that climate and seasonal weather patterns are becoming increasingly difficult to predict. They recognise that climate change is increasingly impacting the whole production cycle and scheduling of farming operations - creating additional challenges for maintaining yields and product quality to meet market demands. Farmers feel that it is now back up to them to experiment and investigate options in production and management like their forefathers had to do, and successfully did, many decades ago.

Potential for change and adopting CASI interventions

Samoan taro farmers expressed the view that they will adopt innovative changes if those changes provide benefit culturally, religiously, financially – and will improve food security for the Samoan people. A good example is the rapid switch to new blight-resistant taro cultivars after the devastation of leaf blight in the early 1990s.

If CASI interventions are to work and be widely adopted by taro farmers, these interventions must be long term and linked to all of the key production and management considerations as discussed (and as outlined above), and must be supported and closely monitored by Ministry of Agriculture and Fisheries officials and advisors.

To alter a country's agricultural sector, particularly one dominated by smallholder farmers, it requires investment in long term outcomes supported by participatory action research, and process that ensure co-operation activities, flexible feedback loops of information, and collaborative buy-in by all sectors of agriculture.

7.4.2 Social and gender factors impacting on Taro-Based Root Crop Farming Systems in Samoa, and implications for CASI

Extensive surveys were conducted of farmers and their families who farm in Samoa using taro-based root crop farming systems. The methodology for this survey is in Section 5.
The questionnaire for this survey can be accessed from Supplementary Information Section 12.2.

A major part of this survey focussed on social and gender factors related to both on-farm and off-farm operations of these farming systems, and on the implications for introduction of CASI in these systems. Men and women were interviewed separately to explore whether there may be different perceptions of the breakdown of roles and responsibilities.

Only a snapshot of the results concerning social and gender factors obtained in this survey is presented here. Full details are being prepared for publication.

Overall, the survey found that currently there is a trend towards females having increasing

roles in the production and marketing of the farm produce in the taro-based root crop farming systems in Samoa. The *Samoa Women's Association of Growers* has now been formed and many women involved in the farming operations in Samoa are active members of this Association.

Part 1. Roles and Responsibilities of Men and Women in the Taro-Based Root Crop Farming Systems in Samoa

Crop Production

Key points:

- Men are predominantly responsible for farm planning, and for environmental and conservation management.
- Men are also predominantly responsible for delivery of the manual on-farm operations, i.e. predominantly responsible for:
    1. Soil preparation before planting
    2. Planting
    3. Application of farm chemicals (fertilisers, herbicides, pesticides)
    4. Irrigation and water management
    5. Weeding
    6. Harvesting
    7. Storage of the harvested crop
    8. Maintenance and repair of machinery, equipment, and fencing.
- While men are predominantly responsible for these manual on-farm operations, women assist with delivering manual on-farm tasks as well – usually delivering about one quarter to a third of the total manual workload required.
- Women are barely involved in storage of harvested crop and maintenance and repair of machinery, equipment, and fencing.
- Children are rarely involved in farm planning, and in environmental and conservation management. They do help out with the manual tasks on farm, and from an early age. Generally, less than 10% of the work effort required for the manual tasks on-farm related to the taro-based root-crop farming systems are delivered by children.
- Based on the results, we found that the roles and responsibilities of women and children in crop production of the taro-based root-crop farming systems is similar to their roles and responsibilities in the crop production of the integrated crop-livestock farming systems in Samoa.

Crop Marketing

Key points:

- Men and women play equal roles in sales planning and/or contracting.
- Men are predominantly responsible for (1) preparing the produce for sale, (2) packing shed operations, and (3) transport of the produce to the market or depot.

- Men and women play equal roles in selling.
- Men and women play equal roles in receiving and handling of money. This contrasts with the cropping phases of the integrated crop-livestock farming systems where women played a dominant role in receiving and handling of money. We found no reason why this may be so.
- Children contribute well to (1) the preparation of the produce for sale, (2) packing shed operations, and (3) selling the produce at market.

Part 2. Access to and Control of Resources by Men and Women in Taro-Based Root Crop Farming Systems in Samoa

Key points:

- Most men in Samoa live and serve (tautua) in the wife's family. Hence, females have good access to, and control of, resources generally.
- Women farm owners have particularly good access to, and control of, the resources of the farm they own.
- In situations where the man is the farm owner, it is apparent that women are generally always well consulted, with shared access to and control of resources.
- Gender equality is now strongly practiced on taro-based root crop farms in Samoa, as indeed it is in Samoan society generally.
- Our analysis examined access to and control of a number of defined farm parameters between men and women in taro-based root crop farms. These were:
    1. Land
    2. Crops
    3. Livestock
    4. Credit
    5. Labour
    6. Agricultural information.

  We could not find any substantial difference between men and women in access to or control of these parameters.
- We also examined the distribution of benefits from the farming operations in the taro-based root crop farms. Again, we could not find any substantial difference in the distribution of the benefits from the farming operations between men and women.

Part 3. Information on Production and Marketing Operations, Sources of this Information, and Access to this Information by Men and Women

Key points:

- There is a wide variety of sources of production and marketing information for farmers of the taro-based root crop farming systems in Samoa. However, our study showed that the farmers of the taro system use these sources differently. The main differences are:

    1. Dominant reliance on the Samoan Ministry of Agriculture and Fisheries (MAF)
        - Ninety five percent (95%) of all those interviewed (male and female) responded that MAF was the main source of production information.
        - Information from MAF was highly credible and well targeted. MAF provides training and information on taro production and marketing, and educated

farmers on market standards for the products.

- The Ministry of Resources and Environment provides good supplementary information on natural resource management.

2. The Samoa-China Agricultural Technical Aid Project (S.C.A.T.A.P) is seen by the taro farmers as a valuable source of information (see Information Box below).

3. As there is a large export market for taro, export companies also provide valuable information on crop production, quality management, and product market requirements.

INFORMATION BOX:

THE SAMOA-CHINA AGRICULTURAL TECHNICAL AID PROJECT

The Samoa-China Agricultural Technical Aid Project (S.C.A.T.A.P.) was initiated in 2010, and has been extended to phase five for the next three years.

The project seeks to harness Chinese technical expertise in agricultural production to help Samoan farmers enhance their yields and move into new areas of production.

The project has focused on four main areas: a seed production base; display of Chinese agricultural technology; centre of agricultural training; and a platform of agricultural exchange and cooperation

The Government of Samoa provided the land for a S.C.A.T.A.P. Demonstration Farm where the new techniques have been implemented and the fruits of the project have been visible.

S.C.A.T.A..S Phase 5 aims to increase the technical level and production capacity of vegetables, citrus and broilers in Samoa. This will involve building new agricultural facilities, providing agricultural machinery and training.

The fifth phase of the project will also focus on constructing a feed mill and other facilities. It will also aim to create 60 new vegetable tunnel houses; planting 1000 high-quality citrus trees; and raising 10,000 broilers per year. Some 80 types of agricultural equipment and machinery are expected to be involved in these installations.

The Government of Samoa through the Ministry of Agriculture and Fisheries (M.A.F.) will be responsible for the project implementation. The M.A.F. will cooperate with the Chinese Expert Team to realise effective implementation of the project.

Part 4. Access to Key Agricultural Inputs and Support Services

Key points:

- Our study examined access to key agricultural inputs and support services under the following assessment criteria:
    1. Not available
    2. Available in limited quantity

3. Available but poor quality
4. Available but not timely
5. Available but expensive

6. Available but have to travel far
7. Readily available.

- We were also provided with information on the following agricultural inputs and support services:
    1. Seed
    2. Fertilisers
    3. Chemical inputs
    4. Labour
    5. Soil testing
    6. Information on machinery
    7. Purchasing of machinery
    8. Advice on the use of machinery
    9. Servicing of machinery
    10. Repairs of machinery
    11. Resale of machinery.
- The strong overall feedback was that many, if not most, of the agricultural inputs and support services required by taro-based root-crop systems farmers in Samoa were *Not Available*. Secondly, if any of these inputs were indeed available, they were expensive.
- Generally, there were very few differences in the way that men and women viewed access to the agricultural inputs and support services.
- It was emphasised that there was a particular lack of soil testing and operational requirements for improving crop nutrition.

Part 5. Take-Home Messages and Implications for CASI

Key points:

- The taro-based root-crop farming systems farmers and their families in Samoa interviewed for this study were different from the farmers and their families interviewed from the integrated crop-livestock farming systems (see Section 7.3.3). Thus, any similarities in responses show consistency across different populations.
- The major take-home message is that there is very little difference between the taro-based root-crop farming systems in Samoa and the integrated crop-livestock farming systems in the:

    (a) roles and responsibilities of men and women in crop production,

    (b) roles and responsibilities of men and women in marketing of their product,

    (c) access and control of resources by men and women,

    (d) views of men and women on information and sources of information for production and marketing operations, and

    (e) access to key agricultural inputs and support services – and the views of men and women related to this

- Any observed differences in any of the parameters in the dot point above were sufficiently small to have little consequence in the implementation of CASI in both these farming systems. We concluded that what applies to one farming system concerning social and gender factors that may impact on implementation of CASI applies equally to the other.

- We could find no major disparities between gender in the taro-based root-crop farming systems in Samoa that may hinder application of CASI to these farming systems, or may hinder the implementation of CASI into management and decision-making both on-farm, and in product marketing.
- We could not find any social, structural, policy, or institutional barriers to the implementation of CASI in these farming systems.
- Benefits of CASI would be shared equally between genders, and indeed equally within families and within the societal family structures.
- The analysis of access to key agricultural inputs and support services provided some keen insights into challenges for implementation of CASI. First, farmers recognised that there was very limited access to all support services for machinery as required to improve soil management, and secondly support services for soil analysis were virtually non-existent as required to improve plant nutrition.

7.4.3 Strengths, Weaknesses, Opportunities and Threats of the existing Taro-Based Root Crop Farming Systems in Samoa, and implications for CASI

The SWOT analysis of Taro-Based Root Crop Farming Systems in Samoa, as outlined in the following table, was undertaken primarily by Samoan farmers, industry representatives, government personnel, and members of the Samoa Project Advisory Committee during facilitated focus group discussions. This was complimented by secondary information sourced from published reports, journal articles, books, and unpublished data.

Strengths, Weaknesses, Opportunities and Threats of the Existing Taro-Based Root Crop Farming Systems in Samoa

1. STRENGTHS

BIOPHYSICAL

- Samoa has many taro varieties available that can strive in different environments including the four (4) varieties resistant to Leaf Blight disease caused by *Phytophthora colocasiae*.
- Taro requires minimum tillage.
- Dry mulching is a common practice in Samoa.
- Taro is easily grown under rain-fed conditions without irrigation.

SOCIAL, INSTITUTIONAL AND GENDER

- Taro is a staple crop in Samoa and has a cultural and dietary importance in the country.
- Intercropping taro with other crops is already practiced in Samoa given the wide spacing between the plants.
- Samoan Ministry of Agriculture and Fisheries strongly supports taro-based farming.
- Available export market for taro in Australia, New Zealand and American Samoa.
- Women are actively involved in the farming activities particularly in marketing.

2. WEAKNESSES

BIOPHYSICAL

- Samoa has limited arable land for Taro or any agricultural activities.
- Most of Taro varieties are long duration crops that take 8-10 months to harvest.
- Taro production is labour intensive particularly in weed management, planting and harvesting which requires more men to do the work and restricts women in the field.

SOCIAL, INSTITUTIONAL AND GENDER

- High competition in export market with other PICs such as Fiji, which also exports Taro.
- There is no market security and price stability driven by high supply.
- Forty (40%) percent of women working in subsistence agriculture are below the below the Basic Needs Poverty Line (Moustafa 2016).
- Gender Policy not being effectively utilised.

3. OPPORTUNITIES

BIOPHYSICAL

- Intercropping taro with other crops such as vegetables during the early growth stage to increase diversity, production, nutrition, income and sustainability.
- The use of short duration Taro variety 'Famasiga' (4 months) could be an alternative to long duration varieties (8-10 months).
- Introduction and use of disease-resistance varieties.

SOCIAL, INSTITUTIONAL AND GENDER

- Taro production offers labor opportunity to locals.
- Potential ventures for local processing of taro for value adding, e.g. taro whisky, chips, bread.
- Intercropping will increase women involvement in marketing, production and postharvest handling and processing not only for taro but for the companion crops.
- Eighty three percent (83%) of the economically inactive people live in rural areas. Women with the highest level of economic inactivity were those aged 15–19 years (95 percent).

4. THREATS

BIOPHYSICAL

- Short fallow periods reduce soil fertility.
- Increasing use of synthetic commercial chemicals, production costs & environmental damage.
- Presence of pests (i.e. insect pest, weeds, and feral pigs) and diseases (Taro Leaf Blight).
- Availability and use of highly toxic pesticides such as Paraquat without restrictions.
- Intensive taro production and mono-cropping which eventually lead to poor soil fertility.
- Climate change. Irregular rainfall and long drought periods disrupt farming schedules and increase in the presence of pests and disease incidence in the field ultimately reduce productivity.

SOCIAL, INSTITUTIONAL AND GENDER

- Social norms that reinforce disadvantages for women are strong in rural communities.

  Poor agricultural infrastructure, lack of soil testing facilities, lack of irrigation infrastructure and cash-poor farmers.

7.4.4 Proposed CASI interventions for the Taro-Based Root Crop Farming Systems in Samoa

The group representing the Taro-Based Root Crop Farming Systems in Samoa who undertook the SWOT analysis (Section 7.4.3, above) then considered possible CASI interventions that may contribute beneficially to production, environmental management, financial returns, gender issues, or social well-being.

This group was made up of key representatives of farmers and their families practicing the Taro-Based Root Crop Farming Systems in Samoa, industry representatives, government personnel, and members of the Samoa Project Advisory Committee. Their views were sought and captured in facilitated focus group discussions. The outcome of this analysis is in the table below.

There was strong consistency and overlap in the CURRENT CHALLENGES and POTENTIAL CASI INTERVENTIONS between the Integrated Crop Livestock Farming Systems, and the Taro-based Root Crop Farming Systems in Samoa. The full set of information relating to the Taro-based Root Crop Farming Systems as generated in this reference group is presented in the table below to ensure that no information is lost.

Possible CASI Interventions for Beneficial Change in the Taro-Based Root Crop Farming Systems in Samoa	
CURRENT CHALLENGES	**POTENTIAL CASI INTERVENTIONS**
Climate change and natural hazards Samoa experiences natural hazards regularly, particularly tropical cyclones, floods and droughts.	CASI interventions could help to improve the resilience of agricultural industries to cyclones and other climate and natural hazards, and particularly could help the agricultural sector to recover after experiencing a cyclone, flood or drought event. CASI could introduce different varieties of crops and breeds of livestock that are more suited to the natural conditions of Samoa, and could assist with recovery after a cyclone.
Declining soil productivity Agriculture in Samoa recorded negative growth rate of 0.9 contribution to GDP in	As suggested by Reeves (2020) CASI could develop and illustrate nutrient

2014 and crop production decreased from 1,200 to 800 g /capita/day between 1980 and 2016. For reference see Iese et al. 2020, and Davila and Wilkes 2020. Productivity and sustainability of many cropping systems are threatened by a decline in soil fertility, soil structure and biological health of soils For reference see Davila and Wilkes 2020.	recycling through different integrated crop and livestock farming system. It was also suggested that: • Cropping systems that are unsustainable and lacking diversity be replaced, • Livestock be introduced, • Use of legumes in crop rotations be increased to lessen the use of N fertiliser and increase soil C and soil N levels, • More genetic research into crops and forages be promoted and supported to increase water-use efficiency, be more competitive with weeds, and be more resistant to diseases.
Lack of soil testing facilities, intensive cultivation and farmers failure to replenish soil nutrients and organic matter No nutrient budgeting by farmers. Nutrient uptake for taro is a very exhaustive compared to sweet potato. Taro uptake 50.3 kg N, 11.6 kg P and 68.1 kg K/ha/season while sweet potato uptake 16.8 kg N, 9.1 kg P and 26.7 kg K (Desai et al. 2018) Intensification of taro production and farmers failure to replenish soil nutrients and organic matter with continuous use of soil resources unsustainably leads to decline in soil fertility.	CASI could bring the following improvements: Test soil on each farm to determine nutrient status of the soils. Test different cover crops and add organic manures to regenerate soils and replenish soil nutrients. Explore better management of fallow and cover cropping during fallow. For instance, as shown in a multi-agroecological site study in Samoa by Iese et al. 2020: • Fallow with mucuna and grass significantly improved soil active carbon stocks upon decomposition. • Mucuna fallow contributed to the largest addition of biomass across all the agroecological sites in Samoa. • Mucuna was also the most superior cover crop for improving soil active carbon and soil biological activities.
Farmers are 'Cash-Strapped' Farm inputs such as commercial fertilisers and pesticides in Samoa are expensive. Many farmers are poor and almost have no cash reserve (for reference see Sulifoa and Cox 2020).	CASI could shift farmers away from the use of expensive inorganic petroleum based external inputs to locally produced organic manures, use of biological and cultural pest control measures, fallowing

Loans are expensive, interest rates are high, and credit is usually restricted.	land, crop rotations and mixed farming techniques.
Loss of traditional knowledge of maintaining soil fertility In volcanic islands, soil fertility was traditionally maintained through long 'bush fallow' periods; on atolls, leaf-fall tended to sustain shallow but fertile soils in diverse agro-forestry systems or growers assembled large amounts of organic matter in heaps or pits for intensive horticulture. Both systems have tended to break down with increasing population pressure and migration. Downward spiral of soil productivity is a real problem for Pacific Island agriculture. Loss of soil carbon is associated with a cascade of problems like structural degradation, declining water holding capacity and increasing incidences of pests and diseases.	Potential CASI interventions could be: • Revive the traditional agro-forestry systems. • Follow appropriate fallow period. • Compost and reuse organic farm wastes. • Develop a model crop and animal farm where the concept of organic waste conversion by Black Soldier Fly (BSF) maggots can be tested, refined and applied.
High input costs, cyclical labour shortage and rural under-employment Cyclical labour shortage affects farm management, while under employment is common in rural areas. Apart from the natural disasters and vulnerability to overseas competition, farming in Samoa must also put up with the high cost of inputs, small markets, low labour productivity, widespread stealing, and sub-standard agricultural infrastructure and support services. Farmers can do very little about these conditions and must rely ultimately on government leadership and direction to create an environment more conducive to farming as a business.	Potential CASI Interventions could be: • Introduction of new farm machinery for planting, harvesting and post-harvest processing of agricultural produce. • Training farmers on CASI practices using modules on the five key components of CASI. • Need for government leadership and institutional support for Samoan smallholder family farms.
Impacts of sea-level rise and increasing soil salinity The occurrence of extreme events such as sea level rise, which has been recorded at around 3-10mm per year since 1994. (for reference see Davila and Wilkes 2020).	CASI could introduce incremental strategies (e.g. introducing drought-tolerant cultivars) to enable coconut production to be maintained through these shocks until the critical threshold of salinisation occurs.

Coconuts may become unviable in low lying areas exposed to long periods of sea-level inundation.	Introduction of alternative crops to replace coconut (e.g. production of sea weed) is an option in the long-run.
Gender concerns in agriculture • Women in Samoa are actively engaged in subsistence farming, marketing of produce and production of value-added goods. At the national level forty (40) percent of women working in subsistence agriculture are below the Basic Needs Poverty Line, • Nationally, 12.8% female-headed households are below the Basic Needs Poverty Line compared to 10.1% of male-headed households, reflecting increased vulnerability for female-headed households, For reference see Moustafa 2016. • Gender Policy not being effectively utilised – There is a general lack of understanding among the staff within the Ministry (MWCSD) of key concepts of gender mainstreaming and what needs to be done at different levels to promote gender equity. Need for training and capacity building of the ministerial staff is recognised at the higher levels of the government.	Solutions through CASI could be: • Collate and promote profiles of women farming and businesses, • Offer support in terms of training and technical support based on current needs and skills assessment.

Based on the current challenges identified for taro-based root crop farming systems in Samoa, potential CASI interventions that can mitigate/address these challenges include –

- Identification and introduction of best taro genetic materials (drought/heat tolerant, higher crop vigor and leaf blight disease resistant).
- Soil testing to determine nutrient status of the soils to optimise the use of the synthetic fertilizer especially nitrogen.
- Testing of different legume (eg. mucuna)/grass cover crops during fallow period as crop rotation option to regenerate soils and replenish soil nutrients.
- Opportunities for integrated livestock systems that are more suited to the natural conditions and changing climate of Samoa.
- Training farmers on CASI practices using modules on the five key components of CASI for sustaining their crop yields.

Best possible synergetic CASI interventions and their combinations which can be validated under field conditions include: Best taro genetic materials to be tested with legumes being incorporated as rotational cover crops during fallow period along with testing of integrated pest and water management options.

7.5 Implications of CASI for Traditional Mixed Farming Systems in Tonga

The Kingdom of Tonga is a small island developing state (SIDS) located in the central Pacific Island region. It is comprised of 36 inhabited islands that are divided into four major administrative island groups, namely Tongatapu, Ha'apai, Vava'u and the two Niua Islands in the north.

Tonga has a landmass of 748 km^2 across 700,000 km^2 of ocean. The population is around 100,000 people and 75% of the population live in rural areas and rely on agriculture and fisheries for food and income. About 75% of the total population of Tonga live on the main island of Tongatapu (our study site for traditional mixed farming systems).

The Tonga Crown owns all lands in Tonga. Commoner males above the age of 16 years old can have access to a bush or tax allotment land of 8.25 acres. Land entitlement passes to the eldest male in the family. Land can be leased from the government and also from other landholders.

This section (Section 7.5) describes the traditional mixed farming systems of Tonga, and the potential of CASI to impart a range of production benefits to these farming systems, and financial and social benefits to the farmers and their families using these systems.

The information has been provided mainly by members of the Tonga Project Advisory Committee, their networks, members of the MORDI Tonga Trust, industry focus group discussions at Tonga Campus of USP, and an extensive survey of farmers and their families who farm in Tonga using traditional farming systems of Tonga. This information was supplemented by government, industry, and science-based publications.

The focus group discussions were facilitated by Taniela Hoponoa. Mr Hoponoa is a highly experienced agricultural specialist, and expert in *Participatory Rural Appraisal*. He is currently National Manager, R2R ILAMS Project, FAO Tonga, and was previously Deputy CEO and Head of Corporate Services Division at the Ministry of Agriculture and Food, Forests and Fisheries.

The methodology for the survey is at Section 5. The questionnaire for the survey of farmers and their families of the traditional mixed farming systems in Tonga is available at Supplementary Information Section 12.1.

Extensive details of the range of crops grown and the techniques of crop management used in the traditional mixed farming systems in Tonga – as obtained in this SRA - are not presented in full in this Final Report. Only summary information and key conclusions are provided here. Full details are being prepared for publication.

7.5.1 Description of targeted farming systems: Traditional Mixed Farming Systems in Tonga

The targets of our study to address traditional mixed farming systems in Tonga were crop rotations that generally contained a long-term fallow. These systems were developed mainly for the satisfaction of royals and nobles, but also became the standard systems to provide good food security. This is exemplified by the need for the farmers to present their first harvest to the nobles.

The timing of crop cycles in the traditional Tongan calendar is aligned to the phases of the moon as well as seasonality. The calendar is a 13-month calendar focusing on yam production. However, the rapid increase in population and the move towards a cash economy has resulted in more intensive farming systems that also utilise a shorter-term fallow, the application of fertiliser, and permanent cultivation of pieces of land. It is now well accepted by farmers of these traditional farming systems that, unfortunately, these more recent modifications are leading to an observed decrease in soil fertility and a rise in pests and diseases.

About 90% of all farmers in Tonga participate in traditional mixed farming systems. Production is mainly for household consumption, cultural exchanges and for market.

Most of the farmers cultivate their own farm allotment or town allotment. The rural garden allotments (api tukuhau) were to be 8.25 acres (3.34 hectares) in size, except in densely populated parts of Tongatapu, such as Hihifo, and the small islands of the Ha'apai and Vava'u groups. Where land was less abundant, holdings were reduced to between 3.00 acres (1.20 hectares) and 6.00 acres (2.40 hectares) and sometimes to just 2.00 acres (0.80 hectare). Town allotments were uniformly 30 poles (0.40-acre, 0.16 hectare). The usual farm size is 4.8 to 8 acres.

For the farmers from outer islands (outside Tongatapu) with no lands on Tongatapu, they co-managed their traditional farming system farms through a traditional cluster farming mechanism called toutu'u. It is a land sharing arrangement enforced by the cluster where the best harvest of yams (or/and other crops) is given to the owner of the land as a lease payment.

The extensive survey in our study of farmers practicing the traditional farming systems in Tonga conducted mainly by our industry partner MORDI (see Appendix 4) provides rich insights into the operations and structures of these farming systems. There has been no other recent study of this scale addressing this farming system in Tonga. It also provides rich guidance for the potential of CASI to assist with substantial and long-lasting benefits to the farmers and communities of Tonga. Only a snapshot of the results of this study is presented here.

In our study, the farm size of the traditional mixed farming systems varied. About 33% of farmers interviewed cultivate up to 4 acres; about 49% cultivate 5-8 acres; 11% cultivate 9-12 acres, and only 7% of farmers cultivated more than 13 acres.

The traditional mixed farming systems of Tonga almost always contain yams in some form - in association with a range of annual and/or perennial crops (food and non-food crops and trees).

For the annual based mixed farming systems yams are mixed with and/or rotated with other root and tuber crops such as giant taro (*Alocasia macrorrhiza*), taro (*Colocasia esculent*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and taro futuna (tannia) (*Xanthosoma sagittifolium*).

For the systems that include fruit or perennial plants such as breadfruits, pawpaw/papaya, pineapples and bananas, there are usually a dominance of non-root crops / vegetable crops in rotation with yams such as tomatoes, cabbages, capsicum, cauliflower, cucumbers, beans.

A few of the more common combinations of mix-rotation crops are described in more detail below in the section *Rotations and Use of Fallow*.

Main crops, varieties, and cultivars

In our study, 85% of the farmers saved their own seed for the next crop, and the remaining 15% mainly bought seed each year from the market for their crops. But the sourcing of seed differed between crops. The following are the percentage of farmers who saved seed for the next crop; for cassava 78%, for yams 52%, for swamp taro 44%, sweet potato 41%, tannia Taro 30%, giant taro 15%, and watermelon 19%.

Labour

In our study we found that it was mainly manual labour that was used for nearly all the operations in the field.

59% of the respondents said that they hired paid part-time labour to work on their farms and 41% said that they did not hire paid labour. 7% of respondents also hired permanent staff to work on the farm. 45% of the respondents hired up to 10 workers at any point of time, working on an average 5 to 10 hours per day and paid 5 to 20 Pa'anga per hour depending upon the type of work.

Soil management

There is extensive soil cultivation and many passes in coming out of the fallow phase into a cropping phase. These cultivations can extend over 2-3 months. The following is a typical sequence in the transition from fallow to cropping.

First Plough (first rough plough, predominantly on panicum grasslands) → First Burning → Second ploughing → Second Burning → Third Ploughing → Ripping/Mounding→ Planting

Our survey shows that farmers recognise problems with continuing to practice this extensive cultivation. Often there are three burnings creating logistical difficulties, and farmers now recognise that there are substantial losses of nutrients and organic matter during these burns. Occasionally, these 'controlled' burns may get out of control especially during times of drought and high temperatures affecting other farmlands and threatening the buildings and homes. This preparation time often spans 2-3 months, and any holdup in any of the operations can set the whole sequence back, causing the best planting times to be missed.

A number of other difficulties were identified in our survey with this traditional form of soil management and cultivation. The mains ones were:

- Limited access to tractor hire due to not enough tractors being available when operations were needed. Tractor rates are high during peak periods affecting schedules and effectiveness of land preparations. Tractor operators (who are provided with the hire tractors) are often inexperienced and the quality of land preparations as a result is often poor.
- Tillage equipment that are available locally is limited to plough, disc, and ripper.
- Poor access to flexible finance mechanisms – limiting timeliness and quality of soil preparation.
- Lack of farming technological skills, and insufficient guidance from advisors or though policy settings on the best (or allowable) times to slash/burn/till.
- Access to farmlands is often short-term with short-term leases, and this arrangement promotes an attitude of 'mining' the soil for short-term gain. Farmers who own registered lands usually take a much longer-term approach to maintenance and building the soils resources.
- There is little planning and management during fallow to maximise the benefit of this time. Fallow lands are often just left to rejuvenate naturally, or used for animal grazing.

A number of key areas were identified by the Tongan farmers practicing the traditional mixed farming systems in our survey to improve soil management. The main ones were:

- Improved policies on lease of lands, for instance ensuring that the conditions of conservation practice are within the terms of the lease, including whole-systems environmental management and regulations on tree removal.
- Improved access to efficient tillage machines (tractors).
- Improved tillage tools and equipment.
- Well-trained machine operators.
- Strategic management of the fallow phase of rotations especially use of improved species and management (e.g. mucuna and other green cover crops) to improve soil conditions and managed panicum grass invasions.
- Improved access to funding.

More information on opportunities to improve soil management through rotations and fallow is presented in the next section, below.

Rotations and use of fallow

As flagged in the preceding section, there is usually a fallow period between cropping cycles. 60% of farmers reported that they would grow their crops for 1-2 years before a period of fallow. 19% reported that they would grow their crops for less than a year before reverting back to fallow. But practices are starting to change. 11% of farmers reported that they are now not practicing fallow at all – a marked departure from the long-held practice of fallow always being incorporated into the traditional mixed farming systems of Tonga.

Concerning the length of the fallow period, (of the farmers that practiced fallowing) 63% reported that the fallow was between 1-2 years, and 37% reported a fallow of one year or less.

The time that a piece of land is fallow can be described in terms of a land utilisation index – the R-factor, where the period of the cropping phase is expressed as a percentage of the total (cropping + fallow) phases (Halavatau and Asgher 1989; Ruthenberg 1983). For traditional mixed farming systems in Tonga, the R-factor is usually between 33% and 66% (i.e. every three years, fallow is for one to two years). Farmers refer to the system being under permanent cultivation when the R-factor is >66%; and to the system being 'sedentary shifting cultivation when the R-factor is <33%.

From our survey, 52% of the interviewed farmers who were practicing the traditional mixed farming systems in Tonga had yams planted on their farm. Yams is seen as the staple part of this farming systems, and results were possibly a little lower than expected as we were just entering the yam-planting season when the survey was taken. 59% had cassava, 33% had sweet potato.; 37% had watermelon; 26% had taro, 22% had talo futuna. There is great diversity in the crops in rotation.

Our survey and additional focus group discussions showed that there is great diversity of crops grown and rotation systems used in the traditional mixed farming systems of Tonga. These are not reported in detail here. The main rotations are only listed below. Further information about each of these rotation systems is at **Appendix 1, Section 11.1.1**.

1. Alocasia + Yams + Colocasia + Banana + Cassava
2. Kava + Yams + Colocasia + Banana

3. Early Yams + Corn + Colocasia
4. Late Yams + Xanthosoma
5. Early Yams + Sweet Potato
6. Watermelon + Cassava
7. Peanuts + Cassava
8. Xanthosoma + Paper Mulberry
9. Cassava rotated
10. Vegetables rotated

Comment is now made on the use of **Slash and Burn** as an integral part of most crop rotations of a typical mixed farming system in Tonga.

Usually, a crop rotation begins with the farmer selecting a new piece of family-owned land that has been inherited through generations. This area has typically been under forest cover for a number of years.

The farmer clears the new land by slash and burn. Although yam is the main crop in the crop rotation cycle, the first crops to be planted are giant taro and plantain or bananas, which are planted straight after clearing. In the meantime, the yam planting material is being pre-germinated before field planting.

Before yams are planted in the field, holes are dug at specific spacing and dimensions. Spacing for yams is about 1.5 meters by 1.0 to 1.2 meters, with holes dug per plant at a depth of 1.0 to 1.2 meters. Thus, during the first year of rotation, the main crops in the field are yams, giant taro, and plantain or bananas.

Some farmers prefer to plant a few more crops once these main crops are stablished, which may include corn, bele (an edible leaf plant), a few papaya trees, sugar cane, and so on according to the farmer’s preference. Yam is the first crop to be harvested at eight to ten months from planting. This early yam crop, which was planted between May and July, is ready for harvest between December and February. In preparation for the harvest, the yam crop is “killed” by removing the vegetative growth about four to six weeks before harvest. This is a traditional process of forcing the yam crop to mature before harvesting.

The giant taro is harvested after twelve months, and the plantain can remain in the area for a number of years because harvesting can be repeated from ratoon crops. Thus, in the first cropping cycle, yams, giant taro, and plantain, being the main crops, remain in the area for different times. As the system develops, a greater variety of crops are planted in the cropping cycle. When the yam is harvested, sweet potato is planted in the yam holes and harvested six months later. When giant taro is harvested twelve months after planting, *Xanthosoma* or *Colocasia esculenta* (Colocasia taro) can be planted to replace it.

The last crop in the cycle, then, is cassava, which will remain in the soil for six to ten months. During all this time, the plantain crop will still be producing at least one crop every year. When this cycle is completed, the area is then left fallow to allow regeneration of nutrients for usually between two to four years.

It is worth noting that cassava is the last crop in this cropping cycle before the land is left fallow because cassava is known to do better in less fertile soils than other food crops.

A Typical Crop Rotation Practiced in a Typical Mixed Farming System in Tonga

Crop rotation in a Traditional Mixed Farming System

	YEAR 1								YEAR 2												YEAR 3												Y 4	Y 5
CROPS	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D		
Yam	P	P	P					H	H	H																								
Alocasia																																		
Plantain																																		
Sweet potato																																		
Xanthosoma																																		
Cassava																																		
Fallow																																		

Notes: Y4 - Year 4; Y5 - Year 5; P – Planting; H - Harvesting

Nutrition

56% of the traditional farmer respondents said that they used inorganic fertilisers for their crops, 19% used only organic fertilizers (e.g. livestock manure, composts). 25% said that they did not add any fertilisers at all.

Watermelon (41%) and yam (7%) were the two main crops for which farmers applied fertilisers, mainly by hand, and generally about one handful per plant.

Water management

74% of the farmers responded in the questionnaires and focus group discussions that they did not irrigate any crop when using the traditional mixed farming systems. 26% of respondents said that they hand irrigated just their watermelon crop, and this was with water from a community water supply system.

Farmers who did irrigated their crops also stated that they would like change to a more efficient system, however, lack of reliable water source, funds, and knowledge were said to be the main obstacles to this change.

Weed control

There are a wide range of weeds affecting traditional mixed farming systems in Tonga. And there are a range of control measures – covering both chemical and non-chemical means. Non-chemical means include (1) Physical: slashing, hoeing, hand weeding, (2) Cultural: mulching, plant spacing, and (3) Mechanical: harrow cultivator, rotary hoeing.

Further details of the main weeds of concern, and the control measures are at **Appendix 1 Section 11.1.2**.

Pest and disease control

Insect pests (67%), mites (37%), cattle (33%) and pigs (33%) were considered as the main pests affecting the crops.

81% of the respondents confirmed using chemical control measures on pests and diseases.

- About 45% of the respondents used Attack and Malathion for insect control on their farms. Attack is an all-in-one insecticide for broad spectrum pest control and Malathion is an organophosphate insecticide.
- Other chemicals include – Orthene, Suncis, Steward, Rogor, Sunthene, Prevathon, Chlorpyrifox, Bifenthrin and Diazinon.

37% of the respondents used non-chemical control measures including:

- Sanitary - sterilising equipment, destroy plants that harbour pests, control insect vectors. 22% of respondents reported using this approach as a part of their non-chemical control measures.
- Cultural - resistance cultivars, crop rotations, fallow, planting time, the mix of cropping. 19% of respondents reported using this approach as a part of their non-chemical control measures.
- Physical - tillage and mowing weeds, fences, nets, noisemakers, traps, hand-picking. 30% of respondents reported using this approach as a part of their non-chemical control measures.
- Biological - Bacillus thuringiensis (BT), chickens. 7% of respondents reported using this approach as a part of their non-chemical control measures.

Products and marketing

Only 7% of all farmers using the traditional mixed farming systems interviewed are subsistence farmers who consumed all the product they grew.

About 93% of the traditional mixed farming systems farmers sell some of what they produce, although the percentage of what they keep and what they sell varies. About 69% of farmers who sell some of their produce still keep about 60% of the production for own use.

Most farmers (82%) sell their produce mainly locally on roadside markets. Only 11% sell their produce at municipal markets. About 18% of farmers interviewed also sell their produce online.

According to 70% of the respondents, marketing is done by the female (mother) member of the family, and 30% said that marketing in their family was done by the male member of the family. According to 22% of the respondents, children (both male and female) also helped in marketing of the produce.

According to the respondents, the changes that could be made to improve marketing the produce are:

- Change sales planning and/or contracting (48% of respondents),
- Change preparation of produce for sale/packing shed (26% of respondents),
- Change transport to market or depot (15% of respondents),

- Change selling method (33%).

Much, or in some cases nearly all of the produce from Traditional Mixed Farms are used for customary and church obligations.

Loss of product remains a major problem. About 81% of farmers experienced loss of up to 60% due to theft. Most farmers lost up to 40% due to damages from roaming livestock.

7.5.2 Social and gender factors impacting on Traditional Mixed Farming Systems in Tonga, and implications for CASI

Extensive surveys were conducted of farmers and their families who farm in Tonga using traditional mixed farming systems. The methodology for this survey is at Section 5. The questionnaire for this survey can be accessed at Supplementary Information Section 12.3.

A major part of this survey focussed on social and gender factors related to both on-farm and off-farm operations of these farming systems, and on the implications for introduction of CASI in these systems. Men and women were interviewed separately to explore whether there may be different perceptions of the breakdown of roles and responsibilities.

Only a snapshot of the results concerning social and gender factors obtained in this survey is presented here. Full details are being prepared for publication.

Part 1. Roles and Responsibilities of Men and Women in the Traditional Mixed Farming Systems in Tonga

Crop Production and Marketing

Key points:

The table below summarises the gendered roles of men and women in the production systems of the following crops - Early yams, late yams, alocasia, Colocasia, Xanthosoma, cassava, sweet potato, plantain, banana and watermelon. The table also presents how the roles have changed over the years and its implications for future projects.

Role of Men	Role of Women	Any Change in Last 10 years, and Reasons for Change	Opportunities Through CASI
PLANNING			
▪ Land management is predominantly men's role as they own land (registered and/or lease holding) ▪ Plan physical activities and inputs (machine work, hand weeding with hoes, chemical spraying etc.)	▪ Mostly involved if and when contributed cash for farming operations e.g., as a permanent corporate worker/employee/ woman is able to provide extra cash and therefore must involve whether as direct payment from salary or	▪ Cash contribution by women for farming through other means of income ▪ When both gender have target crops or commodities in demand	▪ Train more women (and youth) in agriculture and land management ▪ Introduces and promote women preferred crops and cropping systems

	through loans from the bank. ▪ And sometimes if having the desire for certain crops (e.g., paper mulberry, pandanus or vegetables)		
FIELD WORK			
▪ Traditionally and still predominantly role of men. Such as: - Machine operator - Digging of yam pits - Planting of yams - Chemical spraying etc. - Weeding with hoes	▪ More and more women (wives and daughters) assist in many ways, such as: - Preparation of planting materials, - Providing foods and drinks for workers, and - General management (cutting of yams mini setts, application of staking materials) - Some women assist through translating information that are available in English e.g. calculations of chemical solution and names of products and processes.	▪ Farming as main source of income ▪ Some women may have developed some skills formally (formal trainings e.g., more and more female graduated with Diploma and Degrees in agriculture) or informally (learn by seeing) ▪ Sometimes through provision of cash to pay for operational costs	▪ Develop and Improve effective use of machines for farming where both genders can operate ▪ Train both gender in basic farming skills ▪ To increase women leasing of farm-land as it is allowed in the Land Laws
MARKETING			
▪ Men contribute to a lesser extent	▪ More marketing is now done by women including; - Preparing export related paper works - Selling produce in the local market outlets - Selling through public forum such as Facebook advertisement	▪ Women tend to do a better job in marketing of their produce ▪ They also have the tendencies to save and invest money more efficiently	▪ Agricultural commodity development will benefit women, who can be trained and involved in value addition to agricultural products.

	- Transportation of produce to markets etc.		

Most of those interviewed (85%) saw that there were opportunities to change the roles and responsibilities of men and women in the traditional mixed farming systems in Tonga, and that these changes would lead to a number of benefits – the main benefits being:

- Increased income,
- More efficient use of time on the activities,
- Less labour required to complete the tasks
- Less waste and food losses
- Improve biodiversity and the ecosystem.

Part 2. Access to and Control of Resources by Men and Women in Traditional Mixed Farming Systems in Tonga

Key points:

- Male farmers (Father) have dominant access and control of the land and resources.
- Female farmers (mother) have only partial control of land and crops – although the extent of this partial control varies depending on the family from no access to almost complete access.
- Both male and female farmers had access to and control of credit obtained.
- Both male and female farmers found it hard to hire labour for their farms with scarcity of labour being an overall problem in these farming systems.
- Both men and women reported that there was poor access to required information.

Part 3. Information, Main Sources of Information, and Gaps in Information

Key points:

- The main sources of information for the farmers in the study area are – radio, television, online sources, newspaper, other farmers and government and non-government institutions.
- According to 80% of the respondents, about 20% of the agriculture marketing and production related information was obtained through television and newspaper and rest was obtained through radio, internet, institutions and other farmers.
- On local radio (AM & FM) and television, agricultural programs are run by Ministry of Agriculture, Forestry and Fisheries (MAFF) on agriculture, forestry, livestock and food. These programs are designed to address women's activities and information needs.
- NGOs run radio programs on targeted agricultural activities and initiatives. Most programs are targeted to address seasonally appropriate calendar activities for various local crops, conducted in Tongan where technical experts and experienced farmers and women tell their stories.
- National events such as the agricultural shows are podcasted live on radio.

- The type of production information that was sourced using the above sources include – type of crops to plant, planting techniques, application of fertilisers and other agricultural chemicals, integrated pest management, soil management, weather information and organic farming techniques.
- The type of marketing information that was sourced using the above sources include – market demand for different products, market locations, market price of commodities and for advertising.
- 93% of the respondents found the production and marketing information 'highly valuable'.
- 63% of the respondents were members of a group – church (19%); community (26%); government (4%); non-government (4%); private business (7%).

Part 4. Access to Key Agricultural Inputs and Support Services

Key points:

- According to 33% of the respondents, fertilisers were not available, 30% said they were expensive and 15% said they were available in limited quantity.
- According to 37% of the respondents, all agricultural chemicals were expensive, 22% said they were expensive and 15% said they were available in limited quantity.
- According to 30% of the respondents, agricultural labour was not available and, 22% said their availability was limited.
- According to 89% of the respondents, soil testing facilities were absent in the region.
- According to 30% of the respondents, reliable advice on best machinery for agriculture was not available and 30% said their availability was limited.
- According to 56% of the respondents, markets for purchasing new and used machinery was not available and 22% said they were available in limited quantity.
- According to 37% of the respondents, advice on how to set up and calibrate new machinery was not available and 37% said it was available in limited quantity.
- According to 56% of the respondents, quality servicing after purchase of machinery was not available, 19% said it was available in limited quantity.
- According to 67% of the respondents, irrigation water sources and equipment/infrastructure was not available and 15% said they were available in limited quantity.
- According to 67% of the respondents, markets for selling used machinery were not available and 15% said they were available in limited quantity.
- According to 41% of the respondents, quality seed/planting material is readily available and 15% said they had to travel far to purchase quality seed.

Part 5. Take-Home Messages and Implications for CASI

Key points:

- The extensive feedback that this SRA received from farmers and their families of the Traditional Mixed Farming Systems in Tonga shows a highly collaborative and cooperative family structure that operates these farms.

- There is some distribution of roles and responsibilities between men and women, but this is generally not seen as a major impediment to the operations of the farm. Men are generally involved more in the planning of farming operations, both men and women share on-farm production, and women are generally involved in the marketing of product.
- Both male and female farmers had access to and control of credit obtained.
- Both male and female farmers found it hard to hire labour for their farms with scarcity of labour being an overall problem in these farming systems.
- Both men and women reported that there was poor access to required information.
- Both men and women reported some major difficulties being able to access key agricultural inputs and support services, in particular:
  - Soil testing and fertilisers,
  - Agricultural chemicals
  - Good and timely labour
  - Water sources, equipment, and infrastructure for irrigation
  - Support for farm machinery.
- In the spirit of family collaboration, both men and women reported that further planning and distribution of roles and responsibilities between them would improve the farming system.
- Both men and women reported that generally there was good information available to be able to farm using the traditional mixed farming systems of Tonga, and that this was available from a variety of sources, but the main difficulties were then being able to access the inputs and support services to be able to farm according to this information.

7.5.3 Strengths, Weaknesses, Opportunities and Threats of the existing Traditional Mixed Farming Systems in Tonga, and implications for CASI

The SWOT analysis outlined in the following table of existing Traditional Mixed Farming Systems in Tonga was undertaken by Tonga farmers, members of the MORDI Tonga Trust, industry representatives, government personnel, and members of the Tonga Project Advisory Committee during facilitated focus group discussions. This was complimented by secondary information sourced from published reports, journal articles, books, and unpublished data.

Strengths, Weaknesses, Opportunities and Threats of the Existing Integrated Crop-Livestock Systems in Samoa
1. STRENGTHS BIOPHYSICAL • Tonga has arable and fertile land (soil) that can be easily tilled. • cultivation practices (IPMS) are environment friendly. • Minimal use of external inputs, though it is rising. • Mixed cropping optimises use of resources.

- Diversity of crops, trees are already in Tonga – existing traditional and newly introduced varieties farmers are very familiar with.
- Several crop species and cultivars cultivated in one piece of land.
- They host different pests and diseases, so minimizing the spread that can be rapid in a monoculture system.
- Crops introduced into the systems at different times (sequential pattern) and it disturbs building up of pests in the systems.
- It has multi strata (layers) of lower (yams) middle (taro) to higher (banana) thus allows flow of air within the systems and penetration of sunlight.
- Soil moisture is usually maintained in the microclimate of a mixed system.
- Farmer moving around the system removing matured and dry plant parts is a way of keeping the environment clean.
- Gradual harvesting of early crops creates a robust soil management and disturbance to any accumulation of pests in the systems.
- Shifting cultivation and allowing adequate fallow periods controls pests' infestations.
- MORDI TT has a manual of each crop, variety and how to plant them in Tonga.
- Toutu'u system allow access to land for people with no land in Tongatapu.

SOCIAL, INSTITUTIONAL AND GENDER

- Diversity in food sources (from multiple crops cultivated)
- The Tonga Development Bank (TDB) has introduced loan products and financial support services for women's groups and individual women.

2. WEAKNESSES

BIOPHYSICAL

- Unmanaged and less effective fallow systems, (fallow lands are either left to be naturally rejuvenated or used for animal grazing etc).
- Repeated burning (3x), Sometimes, the so-called controlled burning goes out of control (especially during drought period) and affected other farmlands.
- Long waiting of 2-3 months prior to planting.
- Usually missed key planting times because of the weather.
- Decomposition of organic matters is dependent on the climatic conditions.
- High costs of production (esp. on machine time), use of tractors.
- Access to tractor hire usually limited due to limited number of hired tractors, also expensive.
- Tillage equipment that are available locally is limited to plough, disc and ripper.
- Ploughing the land three times damage the soil physical, biological and chemical structure.
- Requires many crop species to complete the system but not always easy to have access to all when needed due to reasons including poor yield, excessing climatic conditions, seeds not available at the market, etc.

- All farmers consulted relied heavily on the rainfall as mean of irrigating their crops.
- High cost of water storage and irrigation facilities restricts their attempts to invest in irrigation.
- The weather patterns are irregular and often rains at unfavourable or undesired times.

SOCIAL, INSTITUTIONAL AND GENDER

- Limited access to farmland for people from outside Tongatapu.
- Crop rotation dictated by lease periods. More farmers are leasing land on short-term basis (1-3 years). Short term leasing allows “mining” of the land nutrients and prevent farmers from adopting crop rotations and CASI interventions that can benefit them in the long-term.
- Limited access to affordable finance.
- Limited access to technical advice from government agencies (research and extension services).
- Limited opportunities to use machines in these farming systems.
- The kava circle is regarded as the place where politics, economics and social issues are discussed. Women have no access to this circle (Renteln, 2005). However, this is changing as the Government of Samoa passed legislation to allow special measures to increase the number of women in parliament to 10 percent (FAO and SPC 2019).
- Challenges for women farmers - lack of funds to buy seeds or pay for help with the harvest, time constraints due to household demands and a focus on handicrafts over subsistence farming by some women.
- The involvement of women and youth is low and therefore the traditional skill transfer mode of father to son training on the field fades quickly.

3. OPPORTUNITIES

BIOPHYSICAL

- Promote and develop sustainable and resilient cropping systems.
- Revive traditional crop rotations, no-till practices and new resilient, disease resistant varieties.
- Managed fallow systems with improved species and compositions.
- Use of green cover crop to; improve soil conditions and to managed panicum grass invasions (e.g. use of Mucuna and other cover crops).
- Improved access to efficient tillage machines (tractors), Improved tillage tools and equipment, and practices.
- No Till or till once.
- Introduce small-medium size weeding machines.
- Promote the use of surface mulching and composts.
- Promote and build human capital on pesticide use, handling, and storage. Link with development of biopesticides and reduction in use of broad-spectrum chemicals and approaches.
- Carry out research to determine sustainable and resilient cropping systems that supports yam production for social and economic purposes.

- Introduces more resilient yams and Colocasia species.
- Research on propagating of yams from seeds as means of developing resilient and higher yield varieties.
- Research and development on appropriate technologies for water harvesting for irrigation.
- Promote and develop soil organic matter in the soil.
- Promote green cover crops to minimize soil exposure.

SOCIAL, INSTITUTIONAL AND GENDER

- Farmer field schools' programs targeting farmer problems and issues.
- Export market available – New Zealand, China, Korea, Japan.
- Further diversification and introduce new varieties (seed saving).
- Improve food security via longer term cropping systems.
- Engage and develop skills amongst youth.
- Finance target lines targeting small holder needs are available (low interest rates, minimum or no collateral, group-based lending).
- More than 80% of farmers are subsistence smallholders in Tonga. About 40 percent of subsistence workers are rural women.
- Improved policies for providers and users of tillage facilities (e.g. conditions on slashing and burning set out clearly, no tillage during wet periods, etc).
- Improved policies on lease of lands (e.g. ensures that the conditions on trees removal and conservation is included on the lease).

4. THREATS

BIOPHYSICAL

- Climate change & Natural disasters: Tonga is most exposed to climate hazards and geohazards Cyclones, storm surges, tornados, floods, earthquakes, volcanic eruptions, and tsunamis are natural events that threaten Tonga.
- Biosecurity Laws: Tonga has struggled to maintain agricultural competitiveness and to meet more stringent biosecurity requirements imposed by international trading partners.
- Pests (including free roaming animals) and diseases infestations affect production.
- Increase decline of soil quality and health.

SOCIAL, INSTITUTIONAL AND GENDER

- Labour shortages (seasonal working scheme); Thefts of crops.
- Women and other vulnerable groups more adversely affected by climate change related disasters due to - low levels of participation in decision making; limited access to productive resources and climate-sensitive livelihoods undertaken by women (small scale vegetable production) and other vulnerable groups (Ministry of Finance and National Planning, 2015).
- Continue urbanization and population of Tongatapu.
- Increase movement of young people to overseas – migration and seasonal labor scheme.

7.5.4 Proposed CASI interventions for the Traditional Mixed Farming Systems in Tonga

CURRENT CHALLENGES	POTENTIAL CASI INTERVENTIONS
Crop rotations Knowledge of the best crop rotations for different circumstances. Some longer-term rotations are 3-5 years and are unable to use the same crop twice in this rotation, such as: ALOCASIA + YAMS + COLOCASIA + BANANA + CASSAVA Yam is the base-crop in this system, but can only be repeated every 5 years. This system usually used by small-scale subsistence farmers and is practiced to serve social obligations and to provide households with stable foods. The cash income from this rotation systems is poor. Farmers leasing land for short-term cannot adopt/practice this system. The system requires many crop species to complete the system but not always easy to have access to all crops when needed due to reasons including poor yield, excessing climatic conditions, seeds not available at the market. Younger generations lack knowledge and skills to implement this “relay” or sequential method of cropping and require guidance from fathers/older generation.	CASI intervention could improve rotation systems: • Research to determine sustainable and resilient cropping systems that supports yam production for social and economic purposes. • Introduce differentyams and Colocasia cultivars which can meet the requirement of short cropping cycle and rotations • Research on propagating of yams from seeds as means of developing resilient and higher yield varieties. Practice yams planting from vine as is being researched in Samoa. • Requires training farmers in appropriate planting times, methods, varieties. • Improved policies on lease of lands (e.g. ensures that the conditions on trees removal and conservation is included on the lease terms). • Explore a different intercropping and rotation combination and pattern for 0-3 years and 0-5 years.
Yam production problems The incidences of pests and diseases (predominantly Anthracnose on yams) has increased in the past two or three decades. Also increases in intensities and severity of impacts. Crops that are not sprayed with fungicides often have zero yield especially when affected at the early (1-2 months) stages. In addition to the pests and diseases problems, the extreme climatic conditions (too dry and/or too wet) exacerbate the severity of the problems.	CASI Interventions could improve yam production: • Crop diversifications and inter-cropping with resistant varieties of yams to prevent movements of pathogens. • Introduction of disease resistant and drought/waterlogging tolerant yam cultivars. • Yam cultivation in Tonga is 100% through vegetative propagations. Maybe there is potential for testing seed propagations as means of developing anthracnose-resistant cultivars.

Managing weeds is a problem in mixed farming systems	• Use of green cover crop to improve soil conditions and to manage panicum grass invasions (e.g. use of Mucuna and other cover crops). • Improved access to funding to improve weed control. • Explore new weed control systems.
Unmanaged and less effective fallow systems	• CASI could better manage fallow systems with improved species and compositions.
Poor tillage practices and burning of slashed biomass	• Use heavy-duty slasher/shredder machines to enable temporary removal of the slashed biomass to allow effective ploughing of the land. • The shredded biomass can either put back as mulch or go into compost heaps for multiple uses – to create more effective ways to manage farm waste. • Improved tillage tools and equipment. Well-trained machine operators. • Develop sound land management policy in which slashing and burning is managed efficiently. • No tillage or plough once.

Based on the current challenges identified for traditional mixed farming systems in Tonga, potential CASI interventions that can mitigate/address these challenges include

- Introduction of no-till to minimum till practice to improve soil health.
- Identification of intercropping and rotation combinations of preferred mixed cropping and pattern for 0-3 years and 0-5 years.
- Identification and introduction of yam and Colocasia cultivars which can meet the requirement of short cropping cycle and rotations.
- Identification and introduction of disease resistant, drought/waterlogging tolerant and higher genetic vigour yam cultivars.
- Introduction of legume (mucuna)/grass cover crops to better manage fellow periods by improving soil health and controlling panicum grass.
- Training farmers for best cropping practices (appropriate planting times, methods and crop varieties).

Best possible synergetic CASI interventions and their combinations which can be validated under field conditions include: Till/minimum till practice with best crop genetic materials to be tested with legumes being incorporated as rotational cover crops during fallow period along with testing of integrated pest and water management options.

7.6 Implications of CASI for Intensive Monocropping Systems in Tonga

See Section 7.5.1 for a general description of the Kingdom of Tonga, its land mass, islands, demographics, administrative arrangements, and land ownership.

This section (Section 7.6) describes the intensive monocropping systems in Tonga, and the potential of CASI to impart a range of production benefits to these farming systems, and financial and social benefits to the farmers and their families using these systems.

The information has been provided mainly by members of the Tonga Project Advisory Committee, their networks, members of the MORDI Tonga Trust, industry focus group discussions at Tonga Campus of USP, and an extensive survey of farmers and their families who farm in Samoa using traditional farming systems of Tonga. This information was supplemented by government, industry, and science-based publications.

The focus group discussions were facilitated by Taniela Hoponoa. Mr Hoponoa is a highly experienced agricultural specialist, and expert in *Participatory Rural Appraisal*. He is currently National Manager, R2R ILAMS Project, FAO Tonga, and was previously Deputy CEO and Head of Corporate Services Division at the Ministry of Agriculture and Food, Forests and Fisheries.

The methodology for the survey is at Section 5. The questionnaire for the survey of farmers and their families of the traditional mixed farming systems in Tonga can be accessed at Supplementary Information Section 12.4.

Extensive details of the range of crops grown and the techniques of crop management used in the intensive monocropping systems in Tonga – as obtained in this SRA - are not presented in full in this Final Report. Only summary information and key conclusions are provided here. Full details are being prepared for publication.

7.6.1 Description of targeted farming systems: Intensive Monocropping in Tonga

The distinguishing features of the intensive monocropping systems in Tonga are:

1. It has a commercial focus with targeted markets for export and domestic consumption.
2. Marketing is highly organised and strategic, and this largely determines decisions and the process of decision-making on farm,
3. Only 10% of Tongan farmers currently undertake intensive monocropping.
4. Farm size is much larger than the traditional forms of farming – usually about 25 acres per holding (c.f. mainly 4 - 8 acres for traditional systems).
5. Production is via an intensive, highly managed system, with usually only one crop planted at a time depending on the season, and the interests of farmers.
6. The most common commercial crops are watermelons, squash, vanilla beans, bananas, taro, cassava, and yams.
7. Squash and vanilla are supplied to high-value niche markets.
8. Root crops and kava are supplied to Tongan communities overseas.

Main crops, varieties, and cultivars

In our study, 81% of the farmers saved their own seed whereas 19% farmers bought seed from the market for their crops. The crops for which farmers saved their own seed are: Cassava (57%), Swamp Taro (29%), Tannia Taro (24%), Sweet Potato (14%), Watermelon (14%), Yam (14%) and Squash (5%).

Labour

In our study we found that manual labour was used mainly for all the operations on the field. 81% of the respondents said that they hired paid part-time labour to work on their farms and 19% said that they did not hire paid labour. 29% of respondents also hired permanent staff to work on the farm. 81% of the respondents hired 5-15 part-time workers at any point of time, working on an average 5 to 10 hrs per day. The workers were paid 5 to 20 Pa'anga per hour depending upon the type of work.

Soil management

A surprising feature from the surveys undertaken in this study was the similarities in tillage practice between the intensive monocropping systems in Tonga and the traditional mixed cropping systems (see Section 7.3.1). In the intensive monocropping systems, there was still extensive soil cultivation, many phases of burning, and many tractor-passes in preparing the land for planting. Many of the logistical difficulties encountered by the farmers of the traditional mixed cropping systems stemming from this extensive cultivation were equally expressed by the farmers using intensive monocropping systems.

Rotations and use of fallow

The intensive monocropping systems in Tonga have no or minimal periods of fallow between crops. These systems are best described as permanent cultivation systems. The R-factor that describes the period of the cropping phase as a percentage of the total (cropping + follow) phases is always >66% for these systems.

Likewise rotations, or indeed the sequence of different crops, are determined mainly by market opportunities and business decisions of the farmer rather than any strategic operations or farming management decision.

Nutrition

Monocropping is input intensive and mechanized. 43% of the intensive monocropping farmer respondents said that they used some form of external fertilisers on their crops, and 57% said that they did not use any form of external fertilisers at all.

The ratio of synthetic/inorganic fertilisers (e.g. NPK, urea) to organic fertilisers (livestock manures, composts) varies. 33% of farmers said they used synthetic fertilisers, and 19% said they used inorganic forms. Of course, in these figures there is a percentage that use some of each form of fertiliser.

Watermelon (14%), squash (14%) and taro (5%) were the three main crops for which farmers applied fertilisers, mainly by hand, and generally about one handful per plant.

Water management

66% of the intensive monocropping farmers responded in the questionnaires that they did not irrigate any crop.

Of the farmers that did irrigate they responded with the following characteristics of irrigation.

1. Source of irrigation water
   - 50% use water from the community water supply
   - 20% use water from harvested rainwater on their property,
   - 30% use water from a bore on their property.
2. Method of irrigation
   - 63% use hand irrigation
   - 25% use sprinkler
   - 12% use drip.
3. Timing of water application
   - Nearly all provide water at night.
4. Labour to irrigate
   - Labour was always reported to be readily available to undertake irrigation operations.
5. Crops that were irrigated
   - There was no clear pattern in our survey. All crops were equally irrigated.

Weed control

There are a wide range of weeds affecting intensive monocropping systems in Tonga. And there are a range of control measures – covering both chemical and non-chemical means. Non-chemical means include (1) Physical: slashing, hoeing, hand weeding, (2) Cultural: mulching, plant spacing, and (3) Mechanical: harrow cultivator, rotary hoeing.

Details of the main weeds of concern, and the control measures are at **Appendix 2, Section 11.2.1.**

Pest and disease control

There are a wide range pests and diseases affecting intensive monocropping systems in Tonga. And there are a wide range of control measures. Details of the main pests and diseases, and the control measures are at **Appendix 2, Sections 11.2.2 and 11.2.3.**

Products and marketing

Key information on products and marketing in the intensive monocropping system in Tonga, from our survey, are as follows:

- The main crops produced by monocropping farmers are – cassava (43%), pineapple (10%), sweet potato (24%), swamp taro (33%), tannia taro (19%), watermelon (19%) and yam (19%).
- 90% of the respondents retained 0-20% of the produce for household consumption, part of which was given for customary and church obligations and another 20% of the produce was lost to theft.
- Monocropping farmers are commercially oriented and sold 60-100% of their produce (that is left after customary obligations, household needs and theft) in the market.

- 62% sell them locally on roadside markets; 14% sold them in municipal markets. 33% sell them online (not exclusive of roadside markets and municipal markets as well).
- According to 33% of the respondents, marketing is done mainly by the female (mother) member of the family and 29% said that marketing in their family was done mainly by the male member of the family. 28% of respondents reported that it was a shared responsibility. According to 24% of the respondents, children (both male and female) also helped in marketing of the produce.
- According to the respondents, the changes that could be made to improve marketing the produce are:
  - Change sales planning and/or contracting (57%)
  - Change preparation of produce for sale/packing shed (14%)
  - Change transport to market or depot (14%)
  - Change selling method (33%).

7.6.2 Social and gender factors impacting on Intensive Monocropping Systems in Tonga, and implications for CASI

Extensive surveys were conducted of farmers and their families who farm in Tonga using intensive cropping systems. The methodology for this survey is at Section 5. The questionnaire for this survey can be accessed at Supplementary Information Section 12.3.

A major part of this survey focussed on social and gender factors related to both on-farm and off-farm operations of these farming systems, and on the implications for introduction of CASI in these systems. Men and women were interviewed separately to explore whether there may be different perceptions of the breakdown of roles and responsibilities.

Where appropriate, distinctions were drawn out between intensive monocropping systems that operate under corporate farming structures, and intensive monocropping systems that operate under family farming structures.

Only a snapshot of the results concerning social and gender factors obtained in this survey is presented here. Full details are being prepared for publication.

Part 1. Roles and Responsibilities of Men and Women in the Intensive Monocropping Systems in Tonga

Crop Production

Key points:

- The roles and responsibilities of men and women in crop production were analysed under a number of defined job tasks. These were:
  - Farm planning
  - Environmental and conservation management
  - Soil preparation before planning
  - Planting
  - Application of farm chemicals - fertilisers, herbicides, pesticides
  - Irrigation and water management

  - Weeding
  - Harvesting
  - Storage of the harvested crop,
  - Machinery, equipment, fencing maintenance, and repair,
  - Others

- In short, there was a very clear distinction in the roles of men and women in crop production within intensive monocropping systems between those that operate under corporate farming structures, and those that operate under family farming structures.
  - With corporate farming structures, there was a dominance in all areas of crop production by men. Women are only slightly involved in all of these production tasks.
  - With family farming structures, there is a more even spread of roles and responsibilities in crop production between men and women, not unlike the spread that was observed with the traditional mixed farming systems of Tonga (as above, Section 7.4.2).

Marketing

Key points:

- The roles and responsibilities of men and women in marketing were analysed under a number of defined job tasks. These were:
  - Sales planning and/or contracting
  - Preparation of produce for sale
  - Transport to market or depot
  - Selling
  - Receival of moneys
  - Other
- (As with crop production) we observed a clear distinction in the roles of men and women in marketing within intensive monocropping systems between those that operate under corporate farming structures, and those that operate under family farming structures. But this distinction was represented in different ways to that observed with crop production (above).
  - With corporate farming structures, there was an even spread between roles and responsibilities in all areas of crop marketing by men and women.
  - With family farming structures, there is dominance in the roles and responsibilities in marketing by women.

Part 2. Access to and Control of Resources by Men and Women in Intensive Monocropping Systems in Tonga

Key points:

- Only a brief snapshot of the extensive information provided by male and female farmers of the intensive monocropping systems of Tonga is provided here.
- We were provided with a great deal of information on access to and control of resources by male and female farmers in both corporate farming structures and family farming structures. This information was classified under the following:

  - Land
  - Crops
  - Credit
  - Labour
  - Agricultural information
  - Non-farm work.

- In general, male farmers have stronger access and stronger control of the land and crops resources, male and female farmers share about equally in access and control of credit, labour and agricultural information. Neither male nor female farmers felt they had any reasonable access or control of non-farm work both within the farm or external to it.
- The dominance of men in having access and control of land and crop resources was stronger with corporate farm structures than with family farm structures.
- The financial benefits from the access and control of resources flowed more to men than women in corporate farm structures. The financial benefits from this access and control were more evenly spread in family farm structures.
- Both men and women on both corporate farms and family farms could see good advantages in adopting the approaches of CASI to their farming. The benefits of adopting CASI were spread about equally across:
  - Increased income
  - More efficient use of time
  - Less requirements for labour
  - Less waste and reduced food losses
  - Improved biodiversity and ecosystems.

Part 3. Information, Main Sources of Information, and Gaps in Information

Key points:

- We could find no differences in the sources of information for the farmers in the intensive monocropping systems of Tonga between corporate farming systems and family farming systems. Furthermore, we could find no differences in the views relating to the value of this information from these sources – the information was always considered as highly valuable.
- The information received was used for both instruction and training.
- The main sources of information were about equally shared between:
  - Radio
  - Television
  - Internet
  - Newspapers
  - Other farmers
  - Institutions.

Part 4. Access to Key Agricultural Inputs and Support Services

Key points:

- Information on access to key agricultural inputs and support services was provided to the project team under the following:
    - Fertilisers
    - Agricultural chemicals
    - Labour
    - Soil testing
    - Reliable advice on best machinery
    - Purchasing new or used machinery
    - Advice on use, set-up, and calibration of machinery
    - Quality servicing after purchase
    - Irrigation
    - Selling used machinery
    - Quality seeds and/or planting materials.
- Across the board, and with both corporate farming structures and family farming structures there was the view that key agricultural inputs and support services are either not available, available only in limited quantities, or if they were available they were unreasonably expensive.
- The big standouts again with both corporate farming structures and family farming structures was that the following were just not available.
    - Soil testing
    - Irrigation equipment and support
    - Advice on selling used machinery.

Part 5. Take-Home Messages and Implications for CASI

Key points:

- There is a clear distinction in roles and responsibilities between men and women in all aspects of crop production and marketing between corporate farm structures and family farm structures. The roles and responsibilities between men and women are offset between the two farming structures such as:
    - Crop production: Men had strong dominant roles and responsibilities in crop production in corporate farming structures, while these roles and responsibilities were shared more evenly between men and women in family farming structures
    - Marketing: The roles and responsibilities in marketing were evenly shared between men and women in corporate farming structures, while these roles and responsibilities were dominated by women in family farming structures.
- Both men and women on both corporate farms and family farms could see good advantages in adopting the approaches of CASI to their farming.
- Information on improving production is readily available that is relevant to both corporate farming structures and family farming structures, but in many cases there was not the required access to agricultural inputs and support services to allow improvements to be made.
- A particular notable response was that for farmers from both the corporate farming structures and family farming structures access to soil testing was not available.

7.6.3 Strengths, Weaknesses, Opportunities and Threats of the existing Intensive Monocropping Systems in Tonga, and implications for CASI

The SWOT analysis outlined in the following table of existing Intensive Monocropping Systems in Tonga was undertaken by Tonga farmers, members of the MORDI Tonga Trust, industry representatives, government personnel, and members of the Tonga Project Advisory Committee during facilitated focus group discussions. This was complimented by secondary information sourced from published reports, journal articles, books, and unpublished data.

Strengths, Weaknesses, Opportunities and Threats of the Existing Intensive Monocropping Systems in Tonga

1. STRENGTHS

BIOPHYSICAL

- Available arable and fertile land (soil) that can be easily tilled.
- Healthy food sources available.
- Sources of seeds and seedling are abundant (many suppliers)
- Increased diversity of cultivars (many cultivars available)
- SOCIAL, INSTITUTIONAL AND GENDER
- Increased mechanization using new technological tools and equipment.
- Farmer field schools' programs target farmer problems and issues.
- Improved farmer technical skills.
- Increased income from exports.

2. WEAKNESSES

BIOPHYSICAL

- Repeated burning affects soil structure and conditions.
- High tillage and ploughing activities degrading soil health.
- Increased use of inorganic fertilizers and chemicals. Poor nutrient management.
- No fallowing.
- Mostly rainfed, low irrigation capacity.
- High postharvest losses.
- No/limited storage capacity or processing.
- Crops are highly seasonal.

SOCIAL, INSTITUTIONAL AND GENDER

- Limited access to farmland.
- Unsafe use of agricultural chemicals.
- Lack of adequate soil testing labs/kits.
- Short term leasing allows "mining" of the land's nutrients.

- The kava circle is regarded as the place where politics, economics and social issues are discussed. Women have no access to this circle.
- Women are marginalized from work in the agricultural sector.
- Challenges for women farmers - lack of funds to buy seeds or pay for help during harvest, difficulty in prioritizing farming activities due to household demands.

3. OPPORTUNITIES

BIOPHYSICAL

- Grow new varieties with good shelf life, can grow beyond seasons (including yams).
- Increase and efficient irrigation systems.
- Reduce to no till systems.
- Increase storage capacity of crops, reduce waste of produce.

SOCIAL, INSTITUTIONAL AND GENDER

- Good and fast source of income to farmers.
- Finance for small holder farmers available (low interest rates, minimum or no collateral, group-based lending).
- Irrigation systems available.
- Export market available.
- Possibility for diversification and introduction of new varieties (seed saving).
- Develop a crop rotation regime that includes land fallow.

4. THREATS

BIOPHYSICAL

- Climate change & Natural disasters: Tonga is most exposed to climate hazards and geohazards Cyclones, storm surges, tornados, floods, earthquakes, volcanic eruptions, and tsunamis are natural events that threaten Tonga.
- Biosecurity Laws: Tonga has struggled to maintain agricultural competitiveness and to meet more stringent biosecurity requirements imposed by international trading partners.

SOCIAL, INSTITUTIONAL AND GENDER

- Labour shortages (seasonal working scheme).
- Theft of crops.
- Pests (including free roaming animals) and disease infestations?

7.6.4 Proposed CASI interventions for the Intensive Monocropping Systems in Tonga

CURRENT CHALLENGES	POTENTIAL CASI INTERVENTIONS
Climate change, natural hazards, and natural disasters Tonga is highly exposed to climate hazards and geohazards. Cyclones, storm surges, tornados, floods, earthquakes, volcanic eruptions, and tsunamis are natural events that threaten Tonga.	CASI could be used to explore different varieties of crops (yams, watermelon, squash, taro) and breeds of livestock that are more suited to the conditions experienced after a cyclone. Increase production of yam using vine as planting materials for non-seasonal production, as the Falaniko Amosa method in Samoa.
Declining soil productivity Productivity and sustainability of monocropping systems are threatened by a decline in the soil fertility, soil structure and biological health of soils.	CASI interventions could be used, as suggested by Reeves (2020) for: • The replacement of cropping systems that are unsustainable and lacking diversity. • Introduction of livestock. • Intensification of the use of legumes to lessen demand for N fertiliser and increase soil C and soil N levels. • Promote and support more genetic research into crops and forages to increase water use efficiency and increase plant resistant weeds and diseases. • Adopt reduced or no till systems
Lack of soil testing facilities, intensive cultivation and farmers failure to replenish soil nutrients and organic matter No nutrient budgeting by farmers.	CASI interventions could improve nutrient management: • Soils must be tested before each cropping season – introduce farmers to on-site soil testing kits. • Test different cover crops and addition of organic manures to replenish soils nutrients • Introduce effective fallow cropping for commercial farmers.

	• Train farmers in nutrient use and budgeting. • Nutrient use and management must support agriculture's contribution to NDCs.
No irrigation and/or poor water management Very few farmers effectively harvest the rainfall for irrigation. The ability of farmers to use water retention measures (surface mulching and composts) is limited. High cost of water storage and irrigation facilities restricts their attempts to invest in irrigation. The weather patterns are irregular causing crop damage. The farmers understanding of the climate change principles and terminologies is very limited.	CASI interventions could improve nutrient management: • Research and development on appropriate technologies for water harvesting for irrigation. • Improve irrigation efficiency and water use. • Promote and develop soil organic matter in the soil. • Further develop and improve daily weather updates so farmers can better utilise weather forecasts and better manage irrigation • Promote policies and regulation for better management of water. • Promote green cover crops to minimize soil exposure.

Based on the current challenges identified for intensive monocropping systems in Tonga, potential CASI interventions that can mitigate/address these challenges include –

- Introduction of an integrated production system which is more diverse and promotes crops (yams, watermelon, squash, taro) and livestock integration for more resilient farming system.
- Introduction of no-till to minimum till practice to improve soil health.
- Identification and introduction of fallow cropping using legumes/grasses to improve soil health and nutrient cycling.
- Promote and introduce improved crop genetic materials which are tolerant/resistant to abiotic/biotic stresses.
- Promotion and training for soil testing before each cropping season to optimise the use of synthetic fertilizers especially nitrogen.
- Testing of efficient irrigation methods (drip irrigation) for efficient water use.

Best possible synergetic CASI interventions and their combinations which can be validated under field conditions include: Till/minimum till practice with best crop genetic materials to be tested with legumes being incorporated as rotational cover crops during fallow period along with testing of integrated pest and water management options.

7.7 Impacts of proposed CASI interventions on the target farming systems of Samoa and Tonga

Impacts of CASI interventions on the target farming systems were assessed using the information and knowledge generated from the research, researchers expert knowledge of the systems, and desktop review relevant information.

From the analyses outlined in Sections 7.3, 7.4, 7.5 and 7.6, it is clear that there are strong parallels in the challenges, opportunities, and potential benefits of CASI across each of the four farming systems studied: (1) Integrated Crop Livestock Farming Systems in Samoa, (2) Taro-Based Root Crop Farming Systems in Samoa, (3) Traditional Mixed Farming Systems in Tonga, and (4) Intensive Mono-Cropping Systems in Tonga.

These strong parallels are expressed in different ways in each farming system, but these parallels nevertheless provide confidence that the implementation of CASI can provide broad-based and multiple benefits to each. The application of CASI will, of course, need to be tailored to the specific needs of each of those farming systems and to the specific needs of the practitioners of those farming systems.

Our analysis has drawn out very clear principles of the impacts and benefits of CASI. Only a brief snap-shot of these impacts and benefits drawn from SRA project are presented in this report. More detailed analysis is being prepared for publication.

CASI targets simultaneous improvements in productivity and ecosystems health to underpin profitability and flow-on benefits to societies. It requires systems change towards greater diversification involving crops, forages, livestock, shrubs and trees. It provides for regeneration of soil health, soil nutrition, soil carbon and other key soil parameters. It also caters for improving rotations, and improvements in the efficiencies of resource-use including water, nutrients, and energy, and improvements in pest and weed management, and genotypes.

7.7.1 Benefits of CASI to farm productivity

Farm productivity across the Pacific region is well below potential and is declining. This decline in productivity is a challenge to the current regional agenda for food security that also embraces biodiversity and environmental protections.

As an example of the decline in farm productivity, agriculture in Samoa recorded a negative growth rate of 0.9 contribution to GDP since 2014 (Iese et al. 2020), and crop production has decreased from 1,200 to 800 g/capita/day between 1980 and 2016 (Davila and Wilkes 2020).

Some of the reasons for this decline as outlined by Davila and Wilkes (2020) are parameters that can be addressed by CASI:

- Decline in the fertility, structure and biological health of soils
- Reductions in the availability of fresh water
- Crops unable to cope with variations in weather events including extreme events
- Use of the best cultivars available
- Inadequate pest and disease control.

Our studies in both Samoa and Tonga have substantiated these reasons, and they have also shown yield penalties from additional biophysical factors such as nutritional management, crop rotations, soil management, and lack of planting material.

Our studies have also shown wide ranges in the yields commonly observed across all crops. This clearly demonstrating the opportunities for CASI to raise production both at the low end, and across production systems generally.

Examples of this range of yields commonly observed from farmer feedback in our study are shown in the table below.

Commonly observed crop yields in Tonga		
Crop	Commonly observed yields kg/acre	Range of yield
Early yam tubers	3000 - 10000	>3-fold
Late yam	4000 - 10000	2.5-fold
Sweet yam tubers	2000 - 8000	4-fold
Xanthosoma tubers	1500 - 6500	5-fold
Colocasia / Common taro	1500 - 6500	5-fold
Alocasia / Giant taro	2000 - 4000	2-fold
Cassava / Manioc	8000 – 12000	1.5-fold
Sweet potato	2000 – 8000	4-fold
Irish potato	2000 – 12000	6-fold

The components of sustainable intensification that could be combined to achieve increases in farm productivity in Pacific Island Countries are outlined elsewhere in this report (Sections 3, 7.3.4, 7.4.4, 7.5.4 and 7.6.4). These management practices proposed by our in-country industry partners include:

- Improving soil management with minimal disturbance, surface and subsoil amendments where appropriate with lime, gypsum, organic materials and major macro-nutrients to stimulate soil biological activity and overall soil health.
- Widening the range of crop options – taro, cassava, yam, triticale, vegetables, pepper, chicken, pigs, cattle sheep and various other legume options.
- Diversifying crop varieties/species – range of planting times, flowering times and crop maturities, and with greater resistance to biotic stresses and tolerance of abiotic stresses (dryness, heat, frost).
- Increasing diverse crop management – differential grazing/defoliation regimes, N timing and forms including more biologically fixed N, cover crops/mulches, differing stubble heights and spreading.
- Promoting livestock integration for enhanced crop, residue, weed and pasture management and N cycling and for diversification of farm income streams.
- Incorporating trees and shrubs to provide a range of ecosystem services, including shade and shelter for livestock as the incidence and magnitude of heat stress for animals is increasing as our temperatures rise and more ‘high heat’ days are experienced. Re-invigoration of ‘adaptive agroforestry’

There are parallels between CASI as proposed for Pacific Island Countries with the concept of Natural Farming as developed and successfully tested for Asian countries by the Japan Natural Farming Association http://www.acc21.org/pdf/AJPN.pd

Natural farming emphasizes: (1) establish ecological harmony; (2) use the vitality of crops and animals; (3) utilize all the resources of the land and (4) promote sustainable farms by integrating livestock breeding and crop production.

These are the same ideals as emphasised by Reeves (2020) who has proposed improvements to cropping systems that are unsustainable and lacking diversity, introduction of better livestock systems, increased use of legumes to lessen the dependence on synthetic fertilisers, build soil carbon and nitrogen levels, and utilise improved genotypes in crops and forages, increase water use efficiency, and improve the ecological management of weeds and diseases.

While it is not possible in our SRA to model exactly the synergistic effect of the individual components of CASI on productivity in the four farming systems studied, there can be no doubt that the changes to management in those farming systems as proposed in this SRA will lead to increased farm productivity. The magnitude and expression of this increased productivity will now need to be tested in the field.

7.7.2 Benefits of CASI to farm financials

The project team wish to acknowledge the extensive input received from farmers and industry in both Samoa and Tonga concerning farm financials for all the crops and farming systems examined in this SRA. This included incomes, expenditure (both fixed and variable costs), gross margins, and gross margin sensitivity analyses with yields and selling prices.

Clear conclusions offered by our project partners in Samoa and Tonga were as follows:

- Farmers need to be able to make decisions on how they can maximize their return without harming their farms
- Smart and informed choices on crop to farm can help farmers financially while preserving their farm
- Reducing costs and expenses can help secure good income and the preservation of the farm
- Crop choices and combinations are required by farmers.

Just a couple of examples are given here to demonstrate the potential of CASI to provide substantial benefits to farm financials.

Example 1. Taro-based root crop farming system in Samoa

Expenditures on taro and those on sweet potato (IB/PR/03) were obtained from experimental study at the University of the South Pacific, School of Agriculture and Food Technology, Samoa in 2016 (see also Desai et al. 2018).

Main expenditures were recorded separately - for both land preparation and crop management including labour and costs of materials for planting, fertilizer management, water management, weeding, harvesting, and preparing the produce for marketing.

The generated data was subjected to gross margin and organoleptic analysis. Crop production cycle for taro and sweet potato was restricted to eight and five months, respectively. The planting geometry of 1MX1M for taro and 0.4MX0.7M sweet potato were followed. The realised yields from taro and sweet potato were 14 and 15 tons per ha respectively. To arrive at gross margin and returns per man hours (M.hr), the sale price for taro and sweet potato were considered at WST800 and WST2000 per ton, and wage rate was considered at WST4 per M.hr.

The per hactare crop production costs for the crops were WST 8170 (taro) and WST15,398 for sweet potato.

To establish 1hactare of taro, 200 M.hr were used with an expenditure of WST 800 while the number for sweet potato was 1122 M.hr and the corresponding expenditure of WST4488.

Planting material costs were WST 5000 for taro and WST 8000 for sweet potato.

For taro, around 250kg.ha^{-1} of complex fertiliser was used at a cost of WST 1250.ha^{-1}. For sweet potato, around for 230kg.ha^{-1} was used at a cost of WST 1150.ha^{-1}.

Weed control for one hectare field required 200 M.hr for taro and cost WST 800 while the figure was 528 M.hr for sweet potato with the corresponding cost of WST 528.

Harvesting cost per hactare for taro and sweet potato crops were WST 320 and WST 1232 respectively.

The gross margin of WST 14,602 for sweet potato was higher compared to WST 2,530 for taro while returns to per M.hr for sweet potato was WST 7.46 and WST 5.27 for taro. The Benefit Cost Ratio (B:C) analysis was 1.37 for taro and 1.97 for sweet potato.

Example 2. Intensive Monocropping Systems in Tonga

Our SRA partners in Tonga, led by MORDI TT undertook comprehensive analyses of farm financials to demonstrate the value and benefits of CASI interventions that would increase yields. Just the *Gross Margins Sensitivity Analysis* of the main commodities considered in our SRA that derives from these analyses are presented below. Full financial analyses are available.

EARLY YAM: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	3,000.00	*6,500.00*	*10,000.00*
0.99	1,021.10	4,468.60	7,916.10
1.97	3,976.10	10,871.10	17,766.10
2.96	6,931.10	17,273.60	27,616.10

AMERICAN TARO / XANTHOSOMA: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	1,500.00	*4,000.00*	*6,500.00*
0.34	-193.5	644	1481.5
0.67	309	1984	3,659.00
1.01	811	3,324.00	5,836.00

COMMON TARO / COLOCASIA: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	1,500.00	*4,000.00*	*6,500.00*
0.46	-6.00	1,144.00	2,292.00
0.92	684.00	2,984.00	5,284.00
1.38	1,374.00	4,824.00	8,274.00

GIANT TARO: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	2,000.00	*3,000.00*	*4,000.00*
0.32	304.00	619.00	934.00
0.63	934.00	1,564.00	2,194.00
0.95	1,564.00	2,509.00	3,454.00

CASSAVA: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	6,000.00	*8,000.00*	*10,000.00*
0.14	194.00	474.00	754.00
0.28	1,034.00	1,594.00	2,154.00
0.42	1,874.00	2,714.00	3,554.00

SWEET POTATO: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	2,000.00	*5,000.00*	*8,000.00*
0.27	-336.75	437.25	1,283.25
0.54	203.25	1,823.25	3,443.25
0.81	743.25	3,173.25	5,603.25

IRISH POTATO: SENSITIVITY ANALYSIS T$/ACRE			
Price T$/kg	**Yield (kg/acre)**		
	2,000.00	*6,000.00*	*10,000.00*
0.65	32.25	2,612.25	5,192.25
1.29	1,322.25	6,482.25	11,642.25
1.94	2,612.25	10,352.25	18,092.25

These examples clearly demonstrate the potential of CASI to lift farm financials through increasing yields, reducing production costs, and increasing selling prices through product quality and market timing.

7.7.3 Benefits of CASI to societies and gender

The potential beneficial impacts of CASI on societal and gender factors in Samoa and Tonga have been addressed comprehensively in Sections 7.3.2, 7.4.2, 7.5.2, and 7.6.2. Our analysis has shown that the multiple benefits that CASI may bring on-farm in Samoa and Tonga have the potential to provide direct and immediate flow-on benefits to societies. Only brief additional comments are made here, and these comments mainly will be about gender.

Just this year (2021), the Pacific Ministers for Women endorsed priorities to accelerate progress towards achieving gender equality across the whole Pacific region through an initiative called *The Pacific Pathway for Gender Equality.* This initiative outlines the importance of women engagement in three key areas: (1) women's' economic empowerment, (2) gender-responsive climate justice, and (3) gender-based violence. Pacific Island governments and all stakeholders are encouraged to ensure that women participate meaningfully in the design and implementation of national and sectoral policies, strategies and plans for women participation and involvement. This applies also to agriculture and food. The observations and analyses of our SRA team on the involvement of women in agriculture in Samoa, and Tonga, provide confidence that the benefits of implementing CASI in Samoa and Tonga would also flow on to women.

In Samoa, recent initiatives include (1) Women in Business Development Inc. (www.womeninbusiness.ws), and (2) The Samoa Women's Association of Growers (swagsamoa@gmail.com). The SRA team is well aware of these initiatives because of the focus of our study, but the advice from our in-country partners is that these are just two of the stand-out examples of initiatives that have elevated women in farming and food systems more generally, and increased their participation throughout the market chain locally and across many, if not all, countries of the Pacific.

Our study has shown that women are increasingly taking leadership roles in farming and the food supply chain, and through such (women-based) organisations, are advising their members, and assisting with the training in a wide variety of areas, including the marketing of their produce within Samoa, Tonga and beyond.

Our study has also shown that in both Samoa and Tonga, women play multiple roles in support of family and community settings and income generation. This is consistent with recent findings of the FAO (2019). Women in farming and agriculture are concurrently engaged in on-farm production of the commodities, and the marketing of those commodities – both on roadsides and through stalls in marketplaces. They are key players in production and the value-adding to their commodities.

Women in agriculture in both Samoa and Tonga are still seen as the primary care givers in the homes, and increasingly they are the ones who are managing the finances of the home and of the farming business. They are increasingly attending training to better their business skills.

The conclusion from our analysis is that CASI would provide an additional mechanism for women to become increasingly involved in the improvements of the farming business, and correspondingly, the benefits of CASI would flow increasingly to improving the social and family standing of women in agriculture.

7.7.4 Benefits of CASI to the environment

A number of previous studies (e.g. Davila and Wilkes 2020) have shown consistent increases in the input of resources required for agricultural production in Pacific island countries over recent decades. This is even under the conditions where agricultural production in Pacific Island Countries has been declining (see for instance Iese et al. 2020).

Water and Water Use Efficiency

About 70% of agricultural systems in the Pacific are rainfed, making them highly vulnerable to variations in rainfall (FAO 2010; Iese et al. 2020). It is well established that degraded soils are less able to absorb water, hold water, and drain excessive water – all factors that decrease the efficiency of use of this water. This also leaves communities, farmers and ecosystems more vulnerable to both flood and droughts (e.g. Huang et al 2020).

Droughts in the Pacific can last for months or even years, and farmers and governments alike are finding it hard to know how to respond while in drought and how to recover from drought after it has broken. There are both (1) the direct effects of dry conditions on plant growth and livestock production, and (2) the secondary effects of the increases in temperatures usually concurrent with drought affecting plant and animal productivity and drying soils further. Our partner organisations and farmers in both Samoa and Tonga drew attention to the lasting impacts of drought that extend even after rains have come through the residual hardness of the soil making cultivation difficult the following season.

In contrast to drought, during heavy rainfall events degraded soils have less water infiltration leading to excessive run-off, possible erosion, and the loss of productive soil into waterways for deposition in river mouths and surrounding areas.

The CASI interventions proposed in this SRA that improve soil structure and health increase the capacity of soils to capture usable water, store this water, and then release this water for both more effective plant growth, and reduced adverse off-site environmental impacts.

There are plans by Governments across Pacific countries to build more dams, in part to be able to utilise incident rainfall more effectively for agriculture. As an example, Samoa already has the Afulilo dam in the Aleipata district and is now planning to build the Alawa dam in the Faleata district. The storage and reticulation infrastructure to better manage water at a catchment scale is being put in place. The challenge now is to use this water more effectively on-farm through the development of improved irrigation technologies and know-how. CASI can provide an answer for better irrigation and water management on-farm.

CASI also provides the opportunity for alternative commodities and plant varieties to be developed concurrently to utilise water more efficiently. Hence these improved plant genotypes when deployed, can contribute also to increasing the water-use efficiency.

CASI can increase water-use efficiency in a number of complementary ways – including through improved soil management, improved irrigation, and improved genotypes.

Nutrients and Nutrient-Use Efficiency

In the volcanic islands of the Pacific, soil fertility was traditionally maintained through long 'bush fallow' periods. On atolls, leaf-fall tended to sustain shallow but fertile soils in diverse agro-forestry systems, or alternatively growers assembled large amounts of organic matter in heaps or pits for intensive horticulture. Both systems have tended to break down with increasing population pressure and migration. The downward spiral of soil fertility and productivity is recognised as a real problem for Pacific Island agriculture.

The traditional knowledge of actively managing and investing in organic residues has been lost in most islands. High temperature and rainfall now lead more readily to increased leaching and loss of nutrients – and this in turn leads to declines in soil fertility which lowers crop yield and productivity.

Overwhelmingly, the advice the SRA team have received from project partners and farmers in both Samoa and Tonga is that improved methods for nutrient budgeting at both the soil and farm scales have to be developed and be available to assist farmers in their management decisions. The need for improved methods of nutrient budgeting is supported by literature studies (e.g. Okali et al. 2018).

To be effective, nutrient budgeting has to take into account the different nutrient demands and extractions of the different crop and land uses. For instance, nutrient requirements are much greater for taro than sweet potato. The study of Desai et al. (2018) provides one example of this difference. Nutrient uptake by taro was shown to be 50.3 kg N/ha/season, 11.6 kg P and 68.1 K/ha/season while nutrient uptake by sweet potato uptake was shown to be 16.8 kg N/ha/season, 9.1 kg P and 26.7 kg K.

Intensification of crop production and the failure of farmers to replenish soil nutrients and organic matter leads to an unsustainable decline in soil fertility.

Even though there was a strong call for better nutrient management from our partner organisations and farmers of all the four farming systems we studied, the lack of soil testing facilities and nutrient management know-how was also identified as major shortcomings restricting the capacity of farmers to make the improvements. This is described in our report in *Access to Key Agricultural Inputs and Support Services* in Sections 7.3.2, 7.4.2, 7.5.2, and 7.6.2.

Many farmers drew out the integrative benefits that CASI could bring to the farming systems studied in this SRA leading to increased soil fertility, better crop nutrition, and increased nutrient use efficiency. Some of the examples that show the potential integrative benefits of CASI for nutrition and nutrient-use efficiency are listed below.

Example 1. Type of fallow

A comparison between a mucuna fallow and a typical grass fallow – both with and without lime and rock phosphate applications recorded a 100% increase of Olsen available P (a measure of plant-available soil phosphorus) with the mucuna fallow at both 6 and 12 months. The mucuna fallow plot also showed a 50% increase in available soil nitrogen at 6 months and a 100% increase after 12 months (Iese et al 2020).

Example 2. Green manuring

A PhD study by Anand (2016) focused on the release of nutrients from green manure that has been applied as mulch. Although green manure from erythrina had higher nitrogen content than green manure from mucuna, most of the nitrogen in erythrina was released very rapidly during the initial stages of decomposition, and much of this was lost and could not be used resourcefully by the taro crop. Conversely, the rate of decomposition and the pattern of release of nitrogen from the mucuna residues were more gradual and synchronized well with the vegetative growth phase of the taro crop.

Example 3. Cultivar selection

The study by Anand (2016) showed significant differences in dry matter accumulation and nutrient-use efficiency per unit of edible dry matter. Taro cultivar Samoa 1 had a higher nutrient-use efficiency for N, P, K, Mg, Mn and Cu than cultivar Samoa 2. However, cultivar Samoa 2 had a higher nutrient-use efficiency than cultivar Samoa 1 for Ca, Fe and Zn.

Example 4. The circular economy and managing waste

Input from our partner organisations and farmers of all farming systems studied in our SRA called for better ways to manage both on-farm and off-farm waste to increase nutrient-use efficiency. There is a call to conduct trials as a part of the next step of this CASI work on better ways to use waste – including from crops, animals, market waste, and food waste. Considerable interest was expressed in the use of the maggots of the black soldier fly to assist with harnessing the nutrients from waste to increase nutrient-use efficiency. Such studies could be in association with post-graduate candidatures.

Chemicals, Chemical-Use Efficiency and Integrated Pest Management.

Extensive information on pest and weed control and the potential for beneficial CASI interventions in the four farming systems studied in this SRA is presented in sections 7.3.1, 7.3.4, 7.4.1, 7.4.4, 7.5.1, 7.5.4, 7.6.1, and 7.6.4. These sections show conclusively the potential benefits of CASI. Only brief additional information is provided now.

Input from our in-country partner organisations and farmers shows that biosecurity threat is a persistent challenge for agriculture production in Pacific Island Countries. Pathogens and pests are a continuous concern. Experience shows that exotic invasive species tend to dominate due to limited natural predators and low genetic diversity - an observation supported by Davila and Wilkes 2020.

One particular noted example that highlighted the multiple impact that biosecurity risk has had on farm production, food security, societal hardship is the widespread outbreaks of taro leaf blight in the 1990s. In Samoa alone, this blight impacted on 55% of the country’s GDP in 1994 and caused annual losses of A$11 million between 1994 and 1999 (Singh et al. 2012; Alexandra et al. 2020; Davila and Wilkes 2020).

Several other biosecurity threats that are rapidly becoming more prominent across Pacific Island Countries are the Coconut Rhinoceros Beetle (CRB), the ‘G’ halotype, and the emerging Bogia Coconut Syndrome (BCS) which are seriously threatening coconut production. Fall Army Worm and Varroa mites are also cause for regional concern and biosecurity awareness raising.

In many cases, these biosecurity threats are becoming a higher risk due to changes in management practice implemented over recent decades. For instance:

1. Traditionally, the dominant bush fallow phase based on guinea grass has provided good disease break. In Samoa, and elsewhere widely across Pacific Island Countries, this bush fallow phase has been continually reduced

from about 15 years duration to an average of about 3 years. In many places this long fallow has been phased out entirely as almost continuous cultivation has taken over.

2. Depletion of soil organic carbon and other associated reductions in soil health has led to increased incidences of pests and diseases as amply demonstrated elsewhere (ACIAR, 2015).

CASI provides the opportunity for greater incorporation of integrated pest management into current, new, and developing agricultural production systems of the Pacific.

7.7.5 Benefits of CASI to climate change resilience

The small island states of the Pacific have long been recognised as being some of the most vulnerable to the impacts of climate change (IPCC, 2014, 2021). Vulnerabilities arise from a range of impacts including those to agriculture and food security (Williams and McDuie-Ra, 2017; Cvitanovic et al. 2016). Communities reliant on agricultural livelihoods have been identified as being particularly at risk, with reductions in yield, increases in crop failure, and pest and disease incursion (Crimp et al. 2017).

The exposure of agriculture and food systems in the Pacific to climate change was addressed comprehensively at the first Regional Consultative Workshop of the Koronovia Joint Working Group on Agriculture (KJWA) held in Fiji in 2019. This workshop which was supported by ACIAR recognised that there are uncertainties about the timing and extent of climate change and its impacts. However, the KJWA confirmed that there is no doubt as to the directions of the change in climate, and key areas of vulnerability. It was also recognised that without interventions many of the current agricultural systems of the Pacific Island Countries will become less viable, and regrettably in some cases impossible.

The Community Based Vulnerability Analysis commonly used in Pacific countries to examine the impacts and vulnerability of climate change considers Vulnerability = (exposure x insecurity)/adaptive capacity. Determining vulnerability through sensitivity response models provides a strong base, but it was also recognised that there needs to be a range of different approaches within agriculture and farming systems to building climate change resilience (Figure 10), and in general, given the magnitude of the threats, increasingly towards substantial modifications.

The KJWA recognised the importance of having a very clear distinction between (1) business-as-usual for incremental improvements to farming and agricultural production, and (2) adaptation responses to climate change. These are not the same thing. Adopting best management practices in production is essential anyway, and in most cases these best practices will also provide a degree of greater resilience to season-to-season fluctuations in weather. But consideration and planning for climate change is at another level altogether.

Individual components of farming systems can be modified separately as in the first ‘bubble’ of *Adjusting Practices and Technologies* of Figure 10, as possible responses to climate change. But modifying individual components separately is not CASI.

The benefit of CASI for climate change resilience is that it is already operating within the level of *Changing Systems* as in the second ‘bubble’ of Figure 10. And concurrently is also starting to provide the framework for examining opportunities for *Transformational Change.*

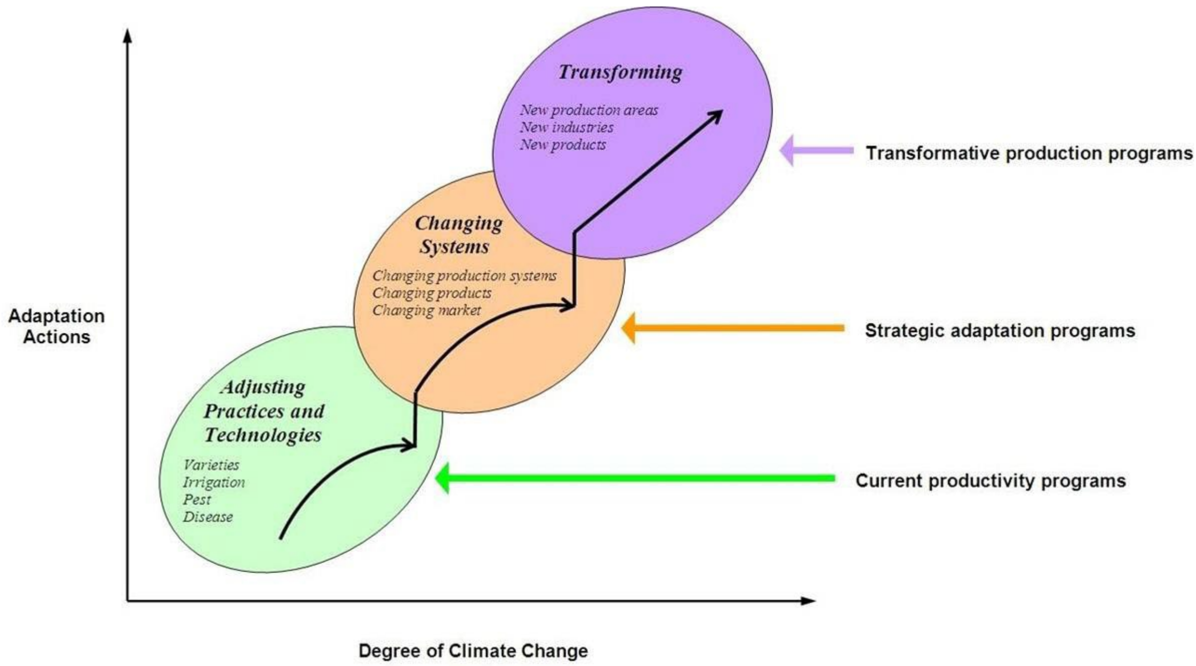

Figure 10. Proposed climate change adaptation framework (bubble diagram). From Ugalde in Report on Regional Consultative Workshop on Koronivia Joint Work on Agriculture, Fiji, 2019.

7.7.6 Benefits of CASI to greenhouse gas emissiveness

The SRA team have assembled an extensive registry of literature on the impacts of individual components of CASI on greenhouse emissiveness of farming systems. This is available on request. The few studies where greenhouse gas emissions have been measured under CASI systems in other parts of the world have been referred to in Section 3 of this Final Report, and are not repeated here. These studies show conclusively that CASI systems have less emissions of greenhouse gases than non-CASI counterparts.

There are no studies as yet on the impact of CASI on greenhouse gas emissions from the four farming systems studied in this SRA, and indeed no studies of emissiveness from any CASI farming system in Pacific Island Countries. Only brief comment is now made on the potential of CASI to reduce emissiveness of the studied farming systems of Samoa and Tonga. These comments will focus on (1) nitrous oxide from agricultural soils, (2) methane from ruminant livestock, (3) livestock waste, and (4) energy.

Information on greenhouse gas emissions from Pacific Island Countries from the World Bank (https://data.worldbank.org/indicator/EN.ATM.NOXE.AG.KT.CE?) shows that in 2019 total greenhouse gas emissions of Samoa were estimated to be 690 ktCO_2e, with total emissions from agriculture of 200 ktCO_2e, or 29%. Of the emissions from agriculture, nitrous oxide makes up 50 ktCO_2e, or 25% and methane makes up 150 ktCO_2e, or 75%.

The contribution of agriculture to total greenhouse gas emissions in Tonga is similar. In 2019, total greenhouse gas emissions of Tonga were estimated at 350 ktCO_2e with total emissions from agriculture of 80 ktCO_2e, or 23%. Of the emissions from agriculture, nitrous oxide makes up 20 ktCO_2e, or 25% and methane makes up 60 ktCO_2e, or 75%.

Emissions from agriculture in both Samoa and Tonga are based on Tier 1 UNFCCC accounting methodologies. Emissions from energy use in agriculture in both countries are accounted under whole-country energy use, and are not readily available.

The high proportion of greenhouse gases from agriculture in the national accounts of Samoa and Tonga show clearly that any reductions in emissiveness of agricultural systems will have a direct impact on the capacity of Samoa and Tonga to deliver their international commitments to reducing emissions through (amongst others) the Paris Agreement (2015).

The key principle in addressing greenhouse emissions from agriculture and any farming system is that emissions are a loss of productive resources from that farming system to the environment. In the vast majority of cases, any management options that increase the efficiency of resource use will, at the same time, also reduce greenhouse gas emissions, and this gives rise to win:win outcomes for both productivity and the environment.

1. Nitrous Oxide from Agricultural Soils

Globally, about 50% of available nitrogen in agricultural soils is lost in gaseous form before being taken up by plants. Most of the gaseous loss is as ammonia, but some of the loss is as nitrous oxide. The extent of these losses depends on the farming system, and ranges from about 85% being lost under highly fertile farming systems where there is liberal use of nitrogenous fertiliser to about only 25% being lost under drier and lower nitrogen conditions. Waterlogged conditions result in high losses of nitrous oxide.

Conditions in the four farming systems described in Sections 7.3, 7.4, 7.5, and 7.6 will generally have low emissions of nitrous oxide due to inherent low levels of available nitrogen in the soils, a dominance of organic forms of nitrogen, and low levels of applying supplementary synthetic nitrogen. However, in all cases, there is the recognition by our partner organisation and farmers of the need to improve crop nutrition including use of supplementary nitrogen. Under these conditions, CASI provides the means to maximise nitrogen-use efficiency and corresponding to minimise any increase in nitrous oxide emissions from those farming systems that may follow.

Other CASI features that will assist to reduce emissions of nitrous oxide include matching nitrogen to crop demand (timing and amount), better soil structure to minimise waterlogging, building soil organic matter (Figueiredo et al. 2018, Harrison-Kirk et al. 2013, Yao et al. 2010), conservation tillage (Kessel et al., 2013, Angela et al. 2017), plant and soil nutrient testing, avoiding burning of crop residues, retaining residues in soil, and encouraging continuous plant cover (McDonald et al. 2021, https://www.agric.wa.gov.au/climate-change/reducing-nitrous-oxide-emissions-agricultural-soils-western-australia).

2. Methane from Ruminant Livestock

Ruminant livestock are relevant in our study especially with the integrated crop-livestock systems of Samoa. Livestock are commonplace in many of the farming systems of Samoa and Tonga, and indeed of Pacific Island Countries generally.

Emissions of enteric methane from ruminant livestock in the farming systems of Samoa and Tonga (mainly cattle and sheep) would be expected to represent between 7% and 14% of the total energy intake in the ingested feed. This is a substantial loss of resources that otherwise could be directed towards the production of meat, milk, or wool. To put this energy loss into perspective, only 3% - 4% of the energy intake ends as saleable animal product – the majority (80% - 85%) is excreted as manure or used for metabolic heat production. Hence the energy that is lost as enteric methane is 3 to 4 times the energy that is converted into saleable product. Possibly, counter-intuitively the poorer the quality of the feed and the lower the nutritional supply to the animal, the higher is this loss value.

CASI is consistent with the management of livestock to minimise methane emissions from cattle and sheep. This management includes improving the quality of pasture or forages and/or supplementing the diets of grazing livestock with grain or other nutrient-rich feeds, managing rotational grazing to maximise the feed value, improving genotypes aimed at achieving shorter finishing times, and improving animal health and husbandry (Giampiero et al. 2019; Henry et al. 2012; https://www.agric.wa.gov.au/climate-change/reducing-livestock-greenhouse-gas-emissions.

3. Emissions from Livestock Waste

Decomposition of animal waste gives rise to emissions of carbon dioxide, methane, and nitrous oxide (IPCC, 2013). Often there are other adverse environmental impacts such as nutrient flow off-site to waterways.

Decomposition of animal waste is also a loss of resources that otherwise could be used productively in agricultural production. For each of the farming systems studied in this SRA, the project team received advice from partner organisations and farmers highlighting opportunities to re-use animal waste more effectively and constructively as organic fertilisers within the principles of CASI and the circular economy.

4. Energy use

The farming systems studied in this SRA use energy for a range of purposes including power machinery, heating, and transport. Energy is also used in the manufacture and supply of materials used on the farm such as fertilisers, pesticides, machinery, and delivery of water. Energy use for tillage increases substantially with increased hardness of soils. Some key areas where CASI will contribute to reduced energy use are adoption of conservation tillage and improved soil structure and health, the circular economy to capitalise on embedded energy in waste and organic inputs to the farm, increased efficiency of fertiliser and chemical applications, and improved irrigation efficiency.

7.8 Information resource base

During the course of this SRA, the project team managed to collate a digital library of 125 references. A small number of these were relevant references in hard copy form sourced from the SPC library and digitised for ease of use. These references are stored in EndNote® and shared amongst the team via the digital 'cloud'; our CASI Information Resource Base. This library has limited access to those who have the EndNote® software. It currently contains full reports and journals that makes it very large and difficult to share by other means than via EndNote® cloud. SPC Land Resources Division (LRD) is currently upgrading its website and will include a CASI project page when the full project commences. LRD has also advertised for a Database Manager who will assist the CASI team to move our restricted access EndNote® digital library to a public online CASI Information Resource Base linked to the CASI webpage.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The SRA has tested the potential of implementing CASI in four farming systems in Pacific Island Countries. A part of this was the development of a *Theory of Change and Modelling of Adoption Pathways* as the framework for further analysis and implementation of CASI. This is presented in Section 7.1 of this report demonstrating scientific impacts of this study. Considerable work was also put into developing the approaches of social science research as outlined in Section 5, and Supplementary Information 12.1. 12.2, 12.3, 12.4.

Regional and international impact will be achieved through publications in the international literature. This includes a review article on the role of CASI in addressing food security, environmental health and resilience in Pacific Island Countries, targeting the journal Global Food Security (IF: 6.0). We also aim to publish key research findings emanating from this SRA in a primary research article. It will discuss how current farm practices, the socio-institutional setup and gender aspects contribute to challenges and opportunities for the implementation of CASI by smallholder farmers in Pacific Island Countries. The target journal for this article is the International Journal of Agricultural Sustainability (IF: 2.3).

While there are considerable scientific impacts from this SRA already, scientific impacts will continually build over time as these pieces of work are utilised in CASI work to follow both in Samoa and Tonga – as well as in other Pacific Island Countries.

8.2 Capacity impacts – now and in 5 years

The SRA was led by experienced researchers and project managers who were able to build capacities in science and project management throughout the team.

In addition, capacities were built outside of the team within our project partner organisations and farmers in Samoa and Tonga to be able to engage in research, development, and extension within their own communities. The building of these capacities is clearly demonstrated in the in-country activities and responses reported in Sections 7.3, 7.4, 7.5, and 7.6. These capacities will continue to be strengthened over the next 5 years at the local levels in both Samoa and Tonga.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

This SRA was to scope the potential of applying CASI to farming systems in Samoa and Tonga to create economic impacts through improved agricultural production systems. Even so, this SRA and the engagement of local farming communities in this SRA has already had economic impact through modification to management practice, and has provided a beacon for what may be possible through implementation of CASI in local agricultural systems, as indicated to the project team, amongst other ways, by senior managers in MORDI TT in Tonga.

8.3.2 Social impacts

A key focus of this SRA was social and gender issues in farming families and regional agricultural communities in Samoa and Tonga as reported in Sections 5, 7.3, 7.4, 7.5, 7.6 and Supplementary information 12.1, 12.2, 12.3, and 12.4. While it is difficult to identify direct social impacts of this SRA on farming families and communities at the moment, the SRA has clearly mapped a pathway for social impacts to derive from any CASI work to follow, as for instance through new ACIAR project CROP 2020/186.

8.3.3 Environmental impacts

In a similar way as above, this SRA has mapped activities that are required through new ACIAR project CROP 2020/186 and other initiatives for implementation of CASI to have a direct beneficial impact on the environment and environmental management. These beneficial impacts will come on stream as the work of this SRA is expanded into the implementation phases.

8.4 Communication and dissemination activities

Communication has been a major strength of this SRA. A total of five focus group discussions (including male and female farmers) were conducted across the two study locations. The main topics that were discussed through these focus group discussions included (1) conservation agriculture, (2) tillage practices, (3) soil nutrition management, (4) improved crops and varieties, (5) water management, (6) pest management, (7) climate change impacts on farm/production, and (8) changing gender roles and responsibilities. The most important feature of these focus group discussions is that they provided a means for open and constructive two-way exchange of information between the SRA project team, and local industry partners and farming communities. More information on these focus group discussions is at Section 5.

A total of 85 personal interviews were conducted with farmers across the four farming systems focussing on current farming systems family, community, and gender social issues in agriculture and food production, and perceived opportunities and benefits for implementation of CASI. These personal interviews also provide a valuable means for open and constructive two-way communication of information. More information on these personal interviews is at Sections 5, 7.3, 7.4, 7.5, 7.6, 7.6, and Supplementary Information Sections 12.1, 12.2, 12.3, 12.4.

Separate Project Advisory Groups (PAG) were formed for Samoa and Tonga. These Groups were made up of prominent leaders in agriculture, land systems, and food - including farmers, farmer groups, government officials, industry stakeholders, educators, and research institutions. The PAGs provided guidance, oversight, and direction to help steer the project. They also assisted with project implementation, and facilitated broader community engagement and involvement with the project. The PAGs were the gateway to genuine two-way communication and collaboration with stakeholders. More information on these focus group discussions is at Section 7.2.

9 Conclusions and recommendations

9.1 Conclusions

A key conclusion from this study is that it is important to define what is meant by CASI, and for this definition to be understood by in-country organisations and farmers. It is an acronym mainly used by ACIAR, but not by other organisations, with the result that there has been some confusion about the definition both within and outside of ACIAR. In simple terms, CASI means 'Conservation Agriculture (CA) based Sustainable Intensification' but various discussions have indicated that for some observers this simply means 'zero till and surface mulching' and nothing more. Zero till and surface mulching was only a small part of the focus in this SRA where sustainable agricultural intensification is the thrust and CA just one component.

First, there are a number of definitions for sustainable intensification, but all are underpinned by the principles of simultaneous increases in productivity and ecosystem health and as some have put it 'producing more with less'. The Oxford Martin Programme Future of Food provides this definition of SI:

> 'The goal of sustainable intensification is to increase food production from existing farmland while minimising pressure on the environment. It is a response to the challenges of increasing demand for food from a growing global population, in a world where land, water, energy and other inputs are in short supply, overexploited and used unsustainably.
>
> Any efforts to 'intensify' food production must be matched by a concerted focus on making it 'sustainable.' Failing to do so will undermine our capacity to continue producing food in the future'

We also conclude that there needs to be consistency in defining and agreeing what are the focusing practices of sustainable intensification. These focusing practices, as we have consistently used in this SRA, are as follows:

- ***Conservation agriculture (CA)*** *- minimal soil disturbance (zero tillage); surface mulches; diverse rotations and integrated production of crops, forages, livestock, trees and shrubs*
- ***Healthy soils with greater levels of soil C and N****, through integrated soil nutrition management, including more legumes*
- ***Improved crops/varieties/livestock*** *that are well adapted; high yield potential; resistance to biotic and abiotic stresses; input-use efficient; higher nutritional quality*
- ***Efficient water management*** *that improves productivity, labour and energy efficiency; helps reduce agricultural water pollution and ultimately uses less water*
- ***Integrated pest management*** *based on farming practices, resistant varieties, natural enemies and judicious use of pesticides*

These principles and practices are scale-neutral and applicable for both smallholder farmers and larger landholders, but their implementation will differ from field to field, farm to farm, region to region and country to country according to local conditions (see Save and Grow in Practice 2016, for global examples of different SI systems). All are of substantial relevance to the farming systems in Samoa and Tonga that we studied in this SRA.

We conclude also that there is still substantial scope to utilise evidence from elsewhere for potential of CASI to improve agriculture and livelihoods in Samoa and Tonga, and elsewhere across the Pacific Island Countries. Evidence of the impacts of sustainable intensification of agri-food systems is gathering strong momentum globally, with several leading scientific journals producing special editions on the topic – for example Nature Sustainability (April 2020); AoB Plants (2020) and the International Journal of Agricultural Sustainability. The rapid increase in publications on sustainable agricultural intensification is drawn out above in Section 3, Background.

There is similar momentum in Australia and New Zealand. The applicability of sustainable intensification in Australia has been described by Reeves (2019) and Reeves (2020). This SRA has also shown that work on developing and implementing CASI in Pacific Island Countries provides, and in the future can provide greater spin-offs to help to identify the new skills and knowledge required for successful implementation and scaling in the Australian and New Zealand agri-food sector as it moves towards greater sustainability and enhanced resilience to future climatic and financial shocks. In Australia an approach is foreshadowed in the Federal Government's Future Drought Fund https://www.agriculture.gov.au/ag-farm-food/drought/future-drought-fund/research-adoption-program.

However, new research is urgently needed in Pacific Island Countries because there has been little progress in building more resilient food systems of late that are essential to provide options for governments, industry/farmers, to achieve effective and efficient adaptation to climate change and cost-effective greenhouse gas emission reductions. This SRA has identified and evaluated the technological, social and policy interventions required to implement and scale these more regenerative agri-food systems, focused on greater sustainability.

It is concluded that CASI has the potential to provide substantial and multiple benefits to all of target farming systems of this SRA and to farming systems generally in Pacific Island Countries. These benefits include production, financial, environmental, social especially related to gender equality, resilience to climate change, and reduced greenhouse gas emissiveness.

9.2 Recommendations

Recommendation 1:

This SRA has shown unequivocally that implementation of CASI would bring multi-level benefits for agriculture, food systems, societies, and the environment in Pacific Island Countries. The same project team of this SRA has submitted a Preliminary Project Proposal (CROP/2020/186) to ACIAR stemming from this SRA that has been invited to the Full Proposal Stage.

It is recommended that additional work and resources be directed to the processes of field-validation – at research sites and on-farm - and implementing CASI in Pacific Island Countries, including but not limited to project CROP/2020/186 currently under consideration by ACIAR.

Recommendation 2:

The SRA created constructive and effective engagement with in-country agricultural institutions, governments, farming organisations, and farmers, and received valuable input to the project through the Project Advisory Groups in both Samoa and Tonga, and extensive surveys of 85 participant farmers.

It is recommended that any further work utilises the significant new partnerships and networks formed in this SRA. This includes effective engagement with in-country farmer representatives, industry and research project partners at all steps in any new work.

Recommendation 3:

This SRA has created a strong foundation for continuing to develop and implement CASI in the farming systems of Samoa and Tonga. The partnerships that have been formed with many groups in each country provide rich opportunity to build progress further, and these partnerships should not be lost. But in addition, any further work should also consider the implications of implementing CASI across Pacific Island Countries more generally than was able to be achieved in this SRA.

It is recommended that any further work continues to focus immediately on Samoa and Tonga, and that new opportunities be explored to broaden application of CASI to other Pacific Island Countries, possibly including through the channels of the Koronivia Joint Working Group on Agriculture, and channels of other potential funding organisations.

Recommendation 4:

The SRA has identified areas where farming in Samoa and Tonga could be improved, and information that is already available from this SRA and elsewhere globally could now be included in education, training, and communication programs. Such programs could be augmented with additional information from field and other studies conducted in Samoa and Tonga as it becomes available over time.

It is recommended that the learnings of this SRA and any further CASI projects are closely aligned with agricultural education and training providers in the Pacific Islands region, especially but not limited to USP. In the short term this could include post-graduate candidatures for field testing of CASI principles in Samoa and Tonga, and in the medium to long term, incorporation of the new knowledge into undergraduate and postgraduate courses as well as industry training.

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11 Appendixes

11.1 Appendix 1: Additional information on the Traditional Mixed Farming Systems of Tonga

11.1.1 Additional information on crop rotations

Our survey and additional focus group discussions showed that there is great diversity of crops grown and rotation systems used in the traditional mixed farming systems of Tonga. Brief information about each of the main rotation systems is below.

1. Alocasia + Yams + Colocasia + Banana + Cassava

- Longer-term systems of 3-5 years.
- Yam is the base-crop i.e. the main harvest of yams will serve the purpose, whether social or economic.
- Requires many crop species to complete the system but not always easy to have access to all when needed due to reasons including poor yield, excessing climatic conditions, seeds not available at the market, etc.
- Crop rotation dictates by the land holding as an issue. More farmers are leasing land on short-term basis (1-3 years).
- Desired crop cultivars may not be available or are available in small quantity.
- Not all (especially younger generations) are having the desired technical and social skills to master this system.
- The element of crops planted in "relay" or sequential" is a tricky technically, and relies on skills handed down to successive generations.
- Mostly applied by small-scale subsistence farmers.
- This system usually practiced to serve social obligations and to provide households with stable foods. Thus, having little economic (cash income) purposes. This means extra costs to farmers may be a challenge to their businesses.

2. Kava + Yams + Colocasia + Banana

- Crop rotation can have maximum of 5-8 years depending on the life of the kava plot
- Kava is the base crop, and is planted for cash (TOP$150 per kilogram locally; TOP$ is the Tongan currency Tonga Pa'aga). Other operations revolve around the Kava phase.
- Consequently, Kava is "soil-selective" and hence the system is more common on land that is highly fertile, well-drained and protected from severe wind damages and salt sprays. Kava is commonly cultivated on forested lands.
- Land tillage is usually less with this rotation system in order to restrict the impacts that are caused by severe droughts.

- Colocasia and banana maybe a risky companion crop to Kava due to their hosting of nematodes. This can be minimised through use of “clean” planting materials and on newly cleared forested site.
- Yam vines on the same plot, can smother and suffocate the young and delicate kava plants.

3. Early Yams + Corn + Colocasia

- This is a dominant early yam production system. Kahokaho is the dominant cultivar – but other fast-growing ones such as Solomone, Kapakau’ikava and Pita are also often used in this rotation.
- Corn is cultivated primarily to provide staking for the yam vines.
- Colocasia (taro) is cultivated in a wider spacing to that of yams to allow space for the yam vines to access sunlight.
- Colocasia is harvestable in 2-3 months after yam harvest and so the crop rotation often maximises production from an 8-10 month production phase.
- Main purpose is to sell both crops for cash income.
- Heavy use of chemicals, particularly fungicides, is common because of the yam’s susceptibility to anthracnose disease.
- Major crop loss often occurs, as in the 2020-21 yam season due to prolonged wet periods.
- Farmers with limited pest and diseases management skills suffer most when conditions are conducive to disease.
- High cost of inputs especially chemicals.
- Fertiliser (NPK) use is increasing to boost yield and product quality, especially on poorer soils – quality is important to maximise cash returns.

4. Late Yams + Xanthosoma

Most information outlined in 1-3 above are relevant here plus,

- Crop rotation maximises at 12-15 months because of the longer life spans of late yams (10-12 months) and Xanthosoma (12-18 months).
- Late yams or Ta’u lahi are usually cultivated 3-5 months prior to the relaying in of Xanthosoma due to its aggressive growth.
- Xanthosoma, if growing very aggressive, are weeded with hoe (huo lafalafa) for up to two months before they are allowed to grow into the system.
- If the mixed system ended up in high plant density, the yams yield often suffer most due to heavy shades and nutrient competition among the companion crops.
- Like 3 above, this system restricts its adoption to short-term leasing lands.
- Sometimes, more Xanthosoma are planted in place of the harvested yam pits. This will mean an extension of 6-10 months after yam harvest.

5. Early Yams + Sweet Potato

Most information outlined in 1-4 above are relevant here plus,

- This system often depends on the state in which the yams are growing. If yams are starting to fade in their growth, sweet potato is inter-planted 2-3 months prior to yam harvest.

- For commercial purposes, the ready-to-harvest yams crown is cut and removed from site to allow early maturity (skin of tubers turns blackish instead of reddish which is sign of juvenility).
- Similarly for production of planting materials (pulopula), the entire yam top is cut and removed from site to: (1) save tubers from further fungal infection, (2) induce early maturity (thickening of tuber skin), and (3) enable open spaces for the sweet potato crops to be planted.
- There is uncertainty in the minds of the farmers who practice this system as to the extent to which yams and sweet potato may be common hosts for a range of pests and diseases that are observed on one or both crops.

6. Watermelon + Cassava

- This system, according to farmers who are practicing it, is often applied towards the end of the cropping cycle where the site will be left for fallow, or the lease holder moves on to another leased land.
- Watermelon is planted a month prior to planting of cassava at different rows or spacing.
- When the melons are ready for harvest (2-3 months), the cassava crops are approximately a foot or two above the ground.
- Cassava is the last crop before fallow.
- Weeding and pest and diseases control practices become restricted in the latter phases of the watermelon crop due to the cassava sticks extending to one foot above ground.
- Sometimes, the chemical spraying affects the two crops differentially depending on the chemical applied

7. Peanuts + Cassava

Similar to 6 above.

- These systems (with cassava involved) is often the one practiced towards the end of the cropping cycle and before fallow.
- Both crops can be planted at the same time with the Xanthosoma mini setts planted deeper (10-20cm) for slow growth.

8. Xanthosoma + Paper Mulberry

- Xanthosoma usually planted 6-10 months prior to planting of paper mulberry so to obtain optimum yield.
- One complete crop rotation (that includes 2-4 harvests of paper mulberry shoots) could last 3-4 years.
- Paper mulberry, being a heavy moisture consumption crop, used to be amongst the last crop in the traditional cropping systems.
- Paper mulberry is now trending amongst the high valued crop for social and commercial purposes. Hence, it is becoming more popular is a two-cropped rotation system as in this case.
- It has a very invasive nature because it produces multiple suckers within the 12-month period leading to the first harvest.
- In the second harvest period (10-12 months after the first harvest) the number if harvestable shoot averages about three. By this time, the site is 100% mono cropped of paper mulberry.

- Long fallow period (5-8 years) is required after the last harvest of paper mulberry since a close netted layer of paper mulberry roots are being formed.
- Heavy tillage and burning of plant biomass are often required in order to bring back some normality to the soil structure and conditions.

9. Cassava rotated

- Cassava is the largest export commodity from Tongatapu.
- It is probably the easiest cash crop to cultivate and manage.
- Cassava grows well from cuttings and so far, there is no notable pests or diseases attacking the crop.
- However, bitter taste cassava due to high cyanide level found in the tuber has its downside on consumption and in marketing them.
- It is a resilient crop in that all local cultivars grow well in poor soils and have high coping mechanism against dry conditions
- Cassava is prone, hence attractive to free roaming pigs that sometimes consume an entire plantation.
- Repeated cultivation of a single site often results in rapid soil degradations and eventual decline in yield.

10. Vegetables rotated

- Some areas are known for farmers cultivating vegetables repeatedly on yearly basis. Such mono-cropping systems of vegetables on same farmland, usually on shifting pattern, lasts 5-10 years.
- Fallow systems are almost not existent in this system because the next cropping cycle follows immediately after harvest.
- The use of agri-chemicals particularly for pests and diseases control increases alarmingly and in large quantities.
- Tillage processes are repeated and often overdoing it with repeated plowing / cultivation and other machine uses.
- There is increased application of synthetic fertilisers to boost production.
- Limited use of organic fertiliser due to added costs and unavailability of organic fertilisers in the local markets.
- There is an increased concern over the use of chemicals due to health threats and occasional fatality cases linked to chemical use.
- The threat on chemical residue on vegetable produces that ended up on families dining tables is real but not scientifically and technically proven.
- Weedicide use is increasing rapidly, contributing to increasing labour costs despite concerns over the detrimental impacts of chemicals on the ecosystems.

11.1.2 Main weeds of concern and control measures

The main weeds of concern in the traditional mixed farming systems in Tonga and the main control measures as identified in the responses questionnaire (See Section 6 methodology and Section 12 Supplementary Information) and as confirmed in the focus group discussions are presented in the following table.

Type of Weeds affecting crops	**No. of respondents**	**% of respondents**
Commelina benghalensis	23	85%
Guinea grass	21	78%
Mimosa pudica	19	70%
Nut grass	18	67%
Biden pilosa	15	56%
Leucaena leucocephala	14	52%
Senna tora	11	41%
Lantana camara	9	33%
Others	3	11%
Type of Controls used		
Non-chemical	21	78%
Chemical	21	78%
Type of Non-Chemical control		
Physical control (slashing, hoe, hand picking)	20	74%
Cultural control (Mulching, plant spacing)	11	41%
Mechanical control (Harrow cultivator, rotary hoe)	8	30%
Others	0	0%
Type of Chemical Control		
Agazone / Paraquat	21	78%
Glyphosphate	15	56%
Others	4	15%

11.2 Appendix 2: Additional information on the intensive monocropping systems of Tonga

The main weeds, pests, and diseases of concern, and the control measures in the intensive monocultural systems in Tonga as identified in the responses questionnaire (See Section 6 methodology and Section 12 Supplementary Information) and as confirmed in the focus group discussions are presented below.

11.2.1 Main weeds of concern and control measures

Main Weeds of Concern and Control Measures in the Intensive Monocropping Systems in Tonga		
	No. of respondents	**% of respondents**
Types of Weeds		
Biden Pilosa	8	11
Lantana camara	2	3
Commelina benghalensis	16	21
Guinea grass	16	21
Nut grass	13	17
Leucaena leucocephala	6	8
Mimosa pudica	13	17
Senna tora	0	0
Others	1	1
Type of Controls Used on Weeds		
Non-chemical	6	23
Chemical	20	74
Type of Non-Chemical Controls on Weeds		
Physical control (slashing, hoe, hand picking)	6	46
Cultural control (Mulching, plant spacing)	5	38
Mechanical control (Harrow cultivator, rotary hoe)	2	16
Others	0	0
Type of Chemical Controls on Weeds		
Agazone / Paraquat	20	53
Glyphosphate	11	29
Za	1	3

Fusilade	1	3
Others	5	13
Methods Use for Spraying Chemical for Weed Control		
Spray with knapsack	15	75
Spray with mist blower	5	15

11.2.2 Main pests of concern and control measures

Main Pests of Concern and Control Measures in the Intensive Monocropping Systems in Tonga		
	No. of respondents	**% of respondents**
Types of Pests		
Pig	8	27
Cattles	3	10
Caterpillars	10	33
Beetles	0	0
Mites	3	10
Aphids	1	3
Rats	1	3
Wild Pigs	1	3
Horse	0	0
Birds	0	0
Chicken	0	0
Others	3	10
Type of Controls Used on Pests		
Non-chemical	10	40
Chemical	15	60
Type of Non-Chemical Controls on Pests		
Sanitary (sterilizing equipment, destroy plant harbour pests, control insect vectors)	7	33
Cultural (Resistance cultivars, Crop rotation, fallow, Planting time, Mix Cropping)	6	29
Physical (Tillage and mowing weeds, fences, nets, noisemakers, traps, hand-picking)	7	33
Biological (Bt *Bacillus thuringiensis*, chicken)	0	0
Others	1	5

Type of Chemical Controls on Pests		
Malathion	9	20
Orthene	7	15
Suncis	7	15
Steward	2	4
Rogor	2	4
Sunthene	2	4
Prevathon	4	9
Chlorpyrifox	0	0
Bifenthrin	3	7
Diazinon	0	0
Others	4	9

11.2.3 Main diseases of concern and control measures

Main Diseases of Concern and Control Measures in the Intensive Monocropping Systems in Tonga		
	No. of respondents	**% of respondents**
Types of Diseases		
Fungus	10	2
Virus	5	1
Bacteria	4	1
Nematode	2	0
Others	6	2
Type of Controls Used on Diseases		
Non-chemical	8	36
Chemical	14	64
Type of Non-Chemical Controls on Diseases		
Sanitary (sterilizing equipment, destroy plant harbour pests, control insect vectors)	6	43
Cultural (Resistance cultivars, Crop rotation, fallow, Planting time, Mix Cropping)	4	29
Physical (Tillage and mowing weeds, fences, nets, noisemakers, traps, hand-picking)	3	21
Others	1	7

Type of Chemical Controls on Diseases		
Kocide	4	14
Manzate	10	34
Sundomil	4	14
Dithane	4	14
Benomyl	3	10
Others	4	14

12 Supplementary information

12.1 Questionnaire for Samoa Integrated Crop-Livestock Farming Systems

https://drive.google.com/file/d/1bHdWCWDL8hK87wIH1IWSTip-_-4BiBMG/view?usp=sharing

12.2 Questionnaire for Samoa Taro-Based Root-Crop Farming Systems

https://drive.google.com/file/d/1uyrOjlf9p0OBBhbaZqM-DGZcZSCOVDUS/view?usp=sharing

12.3 Questionnaire for Tonga Traditional Mixed Farming Systems

https://drive.google.com/file/d/1O6wHAx7xsjBf1LYKG4htTz5stZs-mwpv/view?usp=sharing

12.4 Questionnaire for Tonga Intensive Monocropping Systems

https://drive.google.com/file/d/1x6iYrvnv4bnryreY41QXPN0uGS-EE19L/view?usp=sharing

END OF REPORT