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Farming systems analysis in relation to ACIAR objectives and projects

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Definitions

A farming system (Dixon et al. 2001): a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. Depending on the scale of the analysis, a farming system can encompass a few dozen or many millions of households. For example, the lowland rice farming systems of East Asia may be considered a system.

Farming systems analysis (FSA): Integrates both biophysical metrics and socio-economic metrics to gain an understanding of outcomes at the whole-farm level. Includes the analysis of constraints of production.

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Introduction and scope

A farm can be considered a linked set of natural, social, and designed elements that are intensively managed by humans. A farming business also sits within a household and broader community that can provide opportunities and constraints for agricultural production. A reductionist science approach to researching farming systems would involve the breaking down of the system into its component parts and studying each in isolation. However, the greater emphasis on multi-disciplinary research to provide solutions to agricultural problems in recent years has provided more opportunities to study farming systems. Farming systems analysis (FSA) is defined as a scientific approach that integrates both biophysical metrics and socio-economic metrics to gain an understanding of outcomes at the whole-farm level. The multi-disciplinary nature of FSA makes it challenging to implement in every research project. However, there are cases where a systems approach may lead to additional benefits for farmers (and little unnecessary complexity for the project teams). FSA can be useful when the nature of the problem is uncertain, or the complexity of the system means there are potentially many factors interacting to cause a problem. In this report we will firstly summarise what FSA research is being conducted in ACIAR projects and synthesize where this approach may provide benefits for addressing ACIARs objectives.

This document forms the basis of a strategy for FSA research that will include some goals (to be achieved over the next three years) and a plan to operationalize the strategy within the existing commissioning process used by ACIAR.

What do we mean by Farming System Analysis?

Farming system analysis (FSA) is defined as an approach to scientific research that integrates both biophysical and socio-economic metrics to gain an understanding of outcomes at the whole-farm level. Here we consider FSA to be the detailed examination processes that occur as part of farming systems research (Fig. 1) more broadly. Examples of studies were FSA has been especially useful relate to research questions where we want to understand the stocks and flows of a universal material through the farm components. For example, whole-farm modelling of greenhouse gases (GHG) is increasingly being used to understand the likely impact of different management interventions on emissions (e.g. Mielenz et al. 2017). This can lead to the development of tools such as a greenhouse gas abatement strategies calculator that help farmers evaluate the costs and benefits of management changes. The movement and use of water is another good example (Alliaume et al. 2017). Secondly, FSA can be helpful to compare one set of farming practices against a different set of farming practices. For example, the comparison of organic versus conventional management, or conservation agriculture practices versus traditional cultivation and land management (Rodriguez et al. 2017; Tessema et al. 2015). Importantly the metrics being compared include biophysical measures (e.g. crop productivity and yield) as well as economic (e.g. input costs, profit and labor costs) and social indicators of system state and performance.

The question for ACIAR is firstly when and how the research findings from FSA can be used by smallholder farmers to improve farm sustainability, livelihoods, and reduce poverty. Secondly, how can the needs of smallholder farmers be recognized, articulated and used to drive the development of integrated modelling platforms and their resulting tools. I think the research projects that ACIAR invests in have a role to play in both aspects.

A typical FSA includes several research methods that are usually integrated in some way (e.g. Dalgliesh et al. 2016, Keating & McCown et al. 2001, Carberry et al. 2004) (Table 1, and see Fig. 1). Field trials on research stations are useful for rotational studies with clear controls. Survey data may be useful to characterize the current practices in a region. The trial and survey data may be fed into a farming systems model and then be projected across new sites or scales. Finally, participatory, on-farm trials can be a useful way of engaging with farmers and gathering socio-economic data via case studies. Farming systems models (that usually integrate crop, livestock, economic and social models) are a common component of FSA, but their complexity and detail vary according to the question being addressed. A comprehensive history of agricultural systems modelling is provided by Jones et al. (2017a). Speculating on future advances in this research field the authors identified greater collaboration among public and private researchers, the evolution of Information and Computer Technologies (ICT) to develop user-driven knowledge products, and the molecular genetics revolution as three areas (also see Jones et al. 2017b). The linkage of integrated modelling platforms to data interpretation and management tools, driven by the needs of stakeholders, is the focus of a new generation of agricultural system models (Antle et al. 2017).

One of the key problems encountered with FSA is the desire to consider every element in a farming system at once. This can quickly lead to a high level of complexity that is not always beneficial. There are often limits to the skills of the researchers involved, and the data that can be generated to feed into farming system models given the constraints of the project. In a successful project a process of defining the system boundary in relation to the research questions being addressed should take place. This involves identifying the system components that are most important to include and are feasible to include. However, it is not uncommon to re-assess these "de-scoped" components later in the project. A second constraint on FSA involves the need for primary data to develop robust and useful models. The expectation that great insights can be obtained using a shallow data set to parameterize a complex model is often flawed. Conversely, sometimes very simple models with significant assumptions in relation to biophysical components can be highly informative for directing future research investments.

Table 1. Examples of different research methods or approaches commonly used in the agricultural context. These can be conducted independently but are often integrated in some was as part of a farming system analysis.

Research method	Pros	Cons
Plot trials on research stations	Useful for long-term rotation questions. Highly controlled and easy to publish. Can uncover mechanisms underlying changes. High level of control over endpoint measures.	Very small-scale so often difficult to incorporate livestock, biotic threats, larger-scale production constraints. Difficult to scale out, and sometimes treatments are unrealistic (and often trials are protected from extreme events).
Plot trials on farmers' fields	Useful for long-term rotation questions. Direct interface with farmers. Commercial reality check.	Control is less and sometimes treatments can be compromised. Some level of control over some endpoint measures. Controls can sometimes be non-existent or compromised.
Individual crop/pasture/livestock models and simulations (Holzworth et al. 2014)	Useful for long-term questions, or questions with a risk component (i.e. you wouldn't want to implement in real production context). Useful for assessing the potential impacts of novel technologies and novel management options that are too risky to test in the real world.	Usually only consider the end-point measures associated with a single crop type. Only include the variables that are known and therefore implemented in the model.
Whole-farm models or farming systems models and simulations (Michalscheck et al. 2018, Baudron et al. 2015, Rodriguez et al. 2017)	Useful to assessing the impacts of large and potentially one-way changes to farming systems. Useful for assessing the potential impacts of novel technologies and novel management options that are too risky to test in the real world.	Usually a highly simplified version of the real farming system, so have the potential to over-simplify the likely outcomes. Only include the variables that are known and therefore implemented in the model. Can be linked to participatory research (Carberry et al. 2004)
Surveys of real production practices on farms (Alem et al. 2015)	Can achieve a high degree of reality around input costs, sales and therefore profit margins for farmers. Additional factors that were previously unidentified may come into the data set through open questioning. An opportunity to gather socio-economic data.	Often the surveys are limited in temporal scope (usually cover 1-2 seasons) so variation across time is missed. As these are working farms there is a high degree of spatial variation and some risk of bias. Nothing is controlled by the researchers (except farm selection).
Participatory on-farm trials that involve the farmer as the decision-maker	Enables engagement with farmers. Is reflective of the real constraints and opportunities facing farmers. An opportunity to gather socio-economic data.	Data gathered may be qualitative in nature (note: not always a con). Restricted in scope as this can involve an intensive amount of work with a few farmers. A check on the general applicability of the findings is required.

A brief history of farming systems research in the ACIAR context

The evolution of systems thinking in relation to agricultural research has a long history (on a related topic see timeline of agricultural systems modeling in Jones et al. 2017a, Keating & Thorburn 2018). ACIAR has continually invested in farming systems research (FSR) projects, and these commonly involve multi-disciplinary teams, who attempt to address problems from a holistic perspective. A strict definition of FSR is hard to achieve, however the steps involved in an FSR project are universal (Fig. 1). In 1985 ACIAR sponsored a workshop to identify FSR approaches in which Australian scientists work might complement the approaches being taken in developing countries (Remenyi 1985). At the time ACIAR had four projects in its portfolio that included FSR. FSR was an approach that "seeks to harness the strengths of existing farmer practices and methods to ensure that productivity gains are stable, broadly distributed, environmentally acceptable and achieved at a reasonable cost to farmer and society at large" (Byron 1985, p134). At that time there was much demand for FSR training, and the use of FSR to identify new farming systems (Table 2). However, the development of scientific methods and approaches was only just beginning. Norman and Collinson (1985) wrote "We remain convinced about the value of farming systems research (FSR). However, as we have said for years, we are concerned that it has been oversold. Donor agencies have moved too rapidly in supporting FSR type work before it had time to mature. We believe expectations are too high and that results are expected too quickly." Expenditure on FSR accounted for about 10% of the budgets of different international research centers (the CGIAR centers) (Anderson & Dillon 1985).

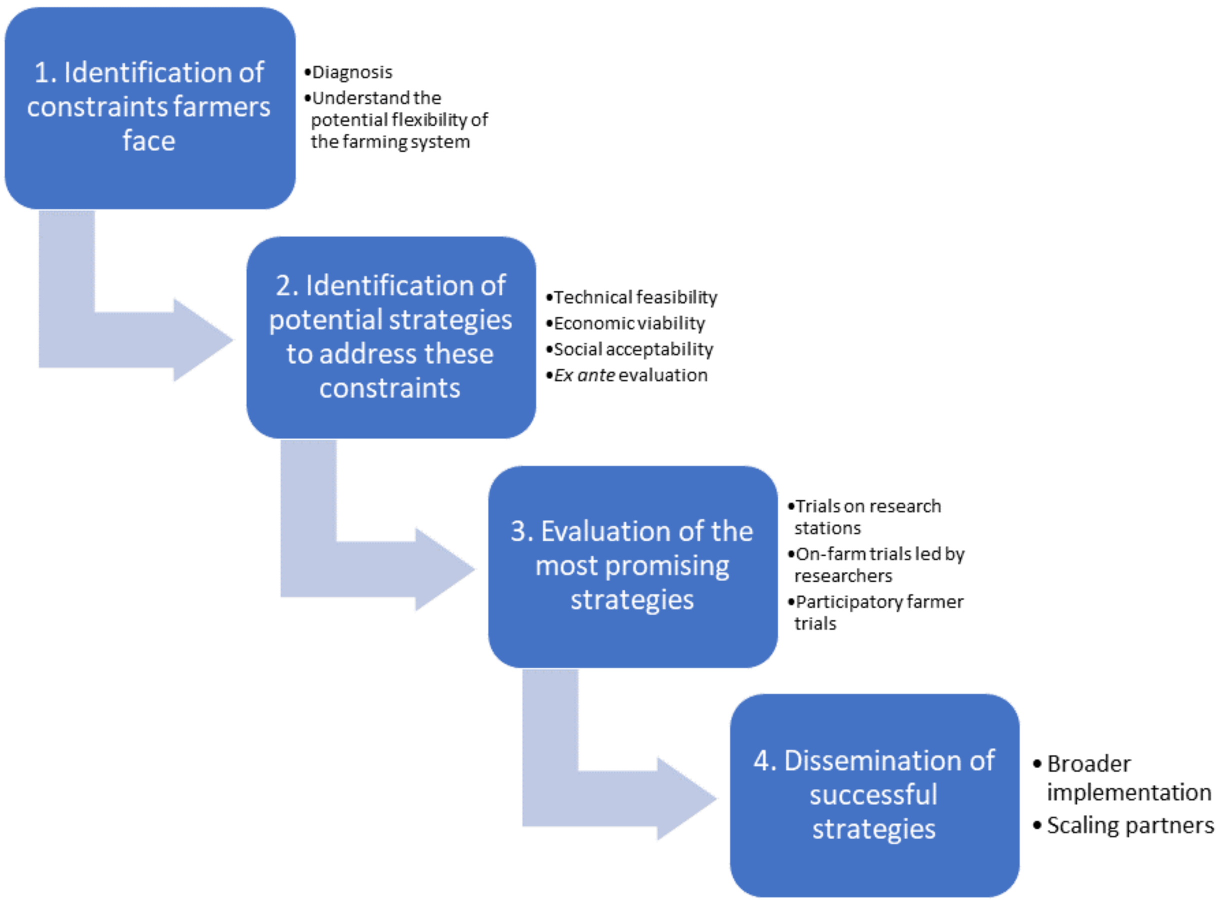

Figure 1. Steps involved in a farming systems research project *(Norman & Collinson, 1985; Connor et al. 2015). Note this is an iterative process, but for simplicity has been represented as a series of steps.*

Throughout the 1990s and into the 2000s there was a broadening of the application of systems models to address applied research questions (Jones et al. 2017a). By the 1990s cropping system models had integrated management modules and therefore could be used to address interactions between crop choice and agronomic practices (Keating & Thorburn et al. 2018). In the 2000's the development of global-scale agricultural data sets fueled insights into resource-use patterns in agriculture at large scales. At a smaller scale the use of simulation modelling for facilitating participatory research in smallholder farming systems was showing some benefits (Carberry et al. 2004). The use of 'virtual' experiments could speed up the identification of potential intervention strategies and engage farmers prior to the evaluation phase of a project. The use of simulation modelling as a scientific tool had taken off, and researchers in Australia were developing decisions support systems that were of greater relevance to farmers and the management decisions they were making daily (McCown et al. 2009, 2012).

Capacity-building of researchers to not only harness the computing technology that was available but also employ systems thinking in their research studies continued to be a challenge. For example, an aim of an ACIAR-funded project on combining cropping systems simulation with farming systems research (CRMASAT, LWR2/1996/049) was to train ICRISAT and partner staff in using simulation modelling. An impact evaluation (5 years after project completion) concluded that APSIM was effective but adoption of the methods by researchers was disappointing. Research capacity based on systems simulation was present in a few teams, but not more extensively employed for R&D activities (McWaters et al. 2005). More recently the greater integration of simulation modelling into projects, especially to help with problem formulation (step 1, Fig. 1), has occurred (Connor et al. 2015). However, we couldn't say this is a common occurrence. In a review of ACIAR projects based in Indonesia, China, Zimbabwe and South Africa, Connor et al. (2015) concluded that without simulation modelling the many positive outcomes of the projects would not have been as successful or achieved in a less efficient manner. The use of modelling was thought to improve the impact and legacy of the projects. However, there was still a call to international donors to help embed systems thinking and modelling capacity into research organizations.

Table 2. Priority demands for farming system research (FSR) collaboration in relation to ACIAR research in five developing countries in 1985. The value indicates a ranking from 1 (lower priority) to 5 (highest priority) developed by the participants a workshop. Adapted from Remenyi 1985, p 11.

	PNG	Philippines	Malaysia	Thailand	Indonesia
Agroecological zone definition	2	1	-	1	1
Strengthening of FSR in national research teams	1	2	4	2	2
Cropping systems modelling	2	2	-	2	3
Rapid rural appraisal methodologies	2	4	2	-	-
Policy studies (food policies and ag. production incentives)	3	3	3	3	4
New farming systems, crop/livestock interaction	4	2	-	4	2
New farming systems, soil conservation	4	2	-	4	2
Methodological issues and research priorities	-	-	1	1	-
Organisational structures appropriate for FSR	-	-	2	4	4
FSR training	3	4	4	1	5

Examples of where Farming System Analysis is currently being used in ACIAR projects

Several current ACIAR investments either explicitly or implicitly involve FSA. Some of these are summarized in Appendix 1. It is relatively common for ACIAR projects to involve multi-disciplinary research teams, however the degree or requirement for integration across domains differs between projects, and sometimes relates to the capacity and interests of the scientists involved. Examples are provided below of two projects with FSA components.

Example project 1: Using big data to assess trade-offs in the use of crop residues as mulches or feedstocks across Sub-Saharan Africa

In response to soil degradation issues associated with agriculture, conservation agriculture (CA) practices have been adopted by many farmers. CA involves less disturbance to the soil profile, retention of crop residues on the soil to maintain ground cover, and rotation with a diversity of crops. Economic studies suggest that it would be profitable for resource-poor farmers to adopt CA or components of CA (Pannell et al. 2013), however there has been low rates of adoption in certain regions. As part of an ACIAR-funded project researchers used an FSA approach to try to understand the benefits and trade-offs in relation to the use of crop residues that may constraint adoption of new practices, such as CA (Rodriguez et al. 2017). The researchers created a linked database of 613 household surveys with a dynamic whole-farm simulation model (APSFarm-LivSim) (Fig. 2). The model was designed to simulate the impacts of alternative allocations of limited resources (land, labour, time, irrigation water, machinery, and finance) on each farm. They could also examine ways to manage these trade-offs. For example, increasing biomass by adding fertilizer to the maize crop or growing forages. The model simulated individual farm households from a large geographic region (from Eastern and Western Kenya), and over a long-time period (99 years of projected climate data). Their findings showed that using fertilizers to increase the biomass from a maize crop could alleviate some of the trade-offs, but the magnitude of benefits in terms of increased farm income was small. They documented the geographic diversity in the different responses to changes in farm resource allocation in each region. This enables more specific management strategies to be developed for each farming context (rather than one solution for all). A full discussion of this modelling approach can be found in Wilkus et al. (2019).

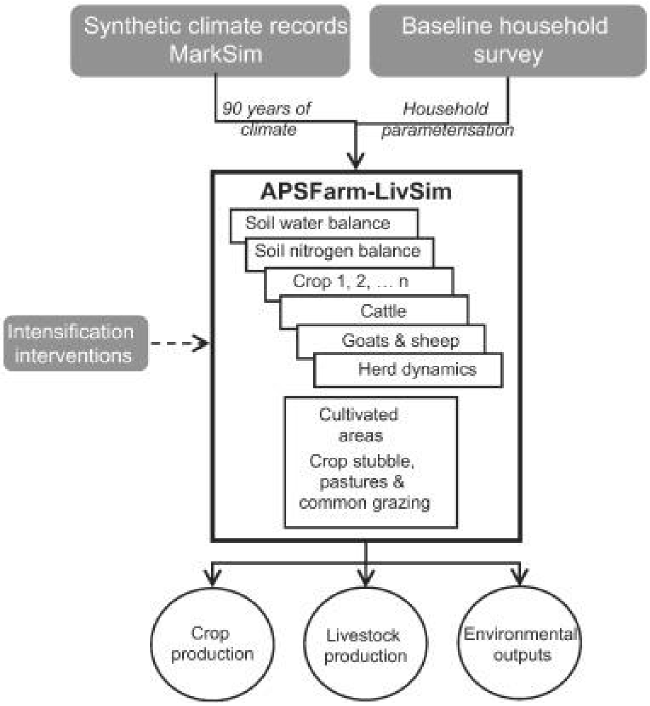

Figure 2. Schematic illustrating the links between the APSFarm-LivSim model with climate and household survey data (Fig. 2 from Rodriguez et al. 2017, and Wilkus et al. 2019).

Example project 2: Promoting socially inclusive and sustainable agricultural intensification

Agricultural intensification is seen as a way of increasing agricultural productivity and thereby addressing poverty and food security issues in developing countries. However, ensuring that all people can capture the benefit of intensification is not straightforward. Accordingly, the aim of this ongoing project is to understand the drivers, develop opportunities, and provide policy options to promote more socially inclusive and environmentally sustainable agricultural intensification in West Bengal and Bangladesh. In these regions there is a perception that there are unused water resources could support increased agricultural production. However, there is a risk that marginalised households may miss out on irrigation opportunities or be negatively affected by the consequences of agricultural intensification. The research team will identify opportunities to manage this risk and promote social inclusivity under different agricultural development scenarios using scenario and trade-off analysis. A major component of the project is to apply modelling tools that enable the integration of qualitative and quantitative data (Fig. 3), and using these models, perform what-if analyses with stakeholders. This process will determine what the trade-offs are between alternative agricultural development trajectories, and what options might offer better outcomes for marginalised households. Importantly, the project team will develop and promote principles underpinning equitable value chains. So far, the team has tested a bio-economic modelling framework to assist farmers and NGOs with decision-making around crop selection, and they are pursuing the development of integrated models based on Fuzzy Cognitive Mapping (simply put a graphical representation of knowledge about a system) to support future scenario analysis of livelihood and value chain options.

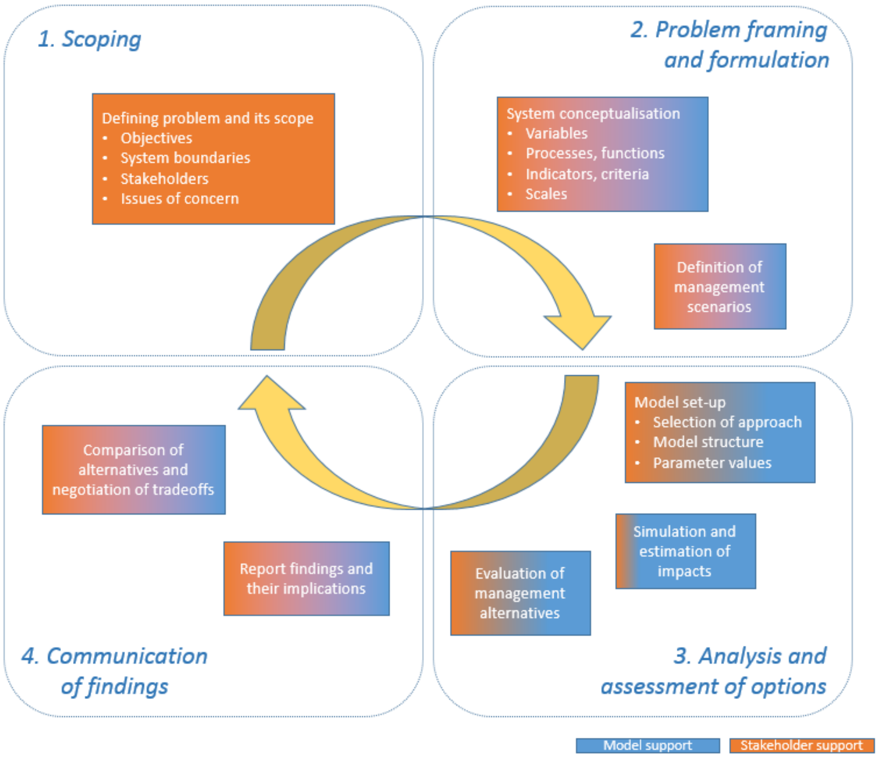

Figure 3. The Integrated Assessment Modelling process as discussed in the project proposal, LWR/2014/072, Promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh. Each step requires a combination of model- and stakeholder-support as indicated by the colour shading.

Can Farming Systems Analysis help to address ACIAR objectives?

Given the complex nature and large data requirements of some FSA projects it is important that the researchers involved have a clear understanding of how the research will support ACIAR objectives. Often the knowledge generated as part of FSA provides the evidence needed to encourage change of practice by farmers and farm business owners. However, to achieve these changes other stakeholders often need to be involved (e.g. agricultural extension staff, training staff, policy makers, incentive schemes). It is rare that FSA alone will solve a problem. In Table 3. I have attempted to clarify some of the impact pathways associated with FSA. However, in each individual project context this pathway to impact would need to fully be described.

There is a role for FSA to guide the scaling process that is required for many of the ACIAR impact pathways to be realized. Connor et al. (2015) notes that "where immediate clients of model development and use are policy developers, researchers or extension agents, there must be a 'clear line of sight' for how the results of this information on practice change is going to be delivered and be of lasting benefit to smallholders." It is not impossible to imagine that FSA approaches and findings could be used to evaluate different scaling strategies using private and public sector collaborations. However, there is little evidence of this in current research investments. A second area where FSA has had limited impact is the extension to value chain research and identification of opportunities or constraints within the value chain (for discussion see Rich et al. 2011).

Table 3. Impact pathway for FSA in relation to ACIAR objectives.

ACIAR objective	Knowledge generated by FSA	Impact pathway
Improve food security and reduce poverty among smallholder farmers and rural communities	FSA can Identify constraints on production of certain crops and livestock.	If these are linked to calorie or nutrient shortages at certain times of the year, strategies can be developed to address the gap.
	FSA can involve an economic evaluation of the costs and revenue from different farming options. Link to how variability in resources or conditions leads to variability in income.	Developing strategies to diversify income or increase profit for farmers.
	FSA can identify constraints on resources that are shared by communities (e.g. water, grazing lands, biodiversity).	Development of more equitable public-private partnerships for shared resources.
Managing natural resources and producing more food more sustainably, adapting to climate variability and mitigating climate change	FSA can include life-cycle assessments and modelling relating to the flows and stocks of carbon, nitrogen, soil, water, etc.	This information can be packaged into decision-support tools. Such tools are critical for informing the long-term sustainability of management interventions.
	FSA can include detailed studies on greenhouse gases (GHG), and comparisons of nett GHG emissions or savings under alternative management scenarios.	This can direct strategies aimed at GHG emissions reductions and the farm, region, or national scale.
	FSA can be used to understand what the optimum crop or livestock production design is (in a theoretical context) using seasonal climate forecasts.	Strategies to increase production, even under variable seasonal conditions. However, often other constraints exist that prevent farmers achieving an optimum design (e.g. market forces, lack of market for certain goods).
Enhancing human nutrition and reducing risks to human health	FSA can be used to understand the trade-offs associated with farming system inputs (e.g. fertilizers, pesticides, other agro-chemicals). Often these inputs have a risk to farm worker health and the environment. FSA can be used to understand the trade-offs to human health associated with intensification of agricultural production (e.g. intensive fish farms, stock feedlots, caged chicken production). Both at the	Strategies to reduce health risks to farm workers from agro-chemicals can be developed.

ACIAR objective	Knowledge generated by FSA	Impact pathway
	farm level and post-farm gate in terms of processing, packaging and distribution.	
	FSA can be used to characterize nutritional gaps for families in certain contexts.	Strategies to diversify diets (through crop and livestock diversity, increased income, or access to different food markets).
	FSA can be used to document the social networks involved in the movement of food through a region or community.	This knowledge can be used to target interventions at influential points in the social network.
Improving gender equity and empowerment of women and girls	If a social dimension is included in FSA, constraints on women and girls in terms of knowledge, training, access to finance, land or other resources can be identified.	Strategies to remove constraints can be developed.
	If research articulates the needs of women and girls around the development and use of agricultural technologies and management changes this information can be used to develop knowledge products from FSA.	Development of tools from FSA that might be more useful and therefore more used.
Fostering more inclusive agrifood and forestry value chains, engaging the private sector where possible	If the scope of the FSA includes value chain stakeholders and articulates their needs.	Development of tools that can foster competitive and complementary interactions between stakeholders.
Building scientific and policy capability within our partner countries	The capacity to conduct FSA can potentially be present in our partner countries but see details below on capacity building.	

Developing capacity to conduct Farming System Analysis research

Whilst the capacity to conduct FSA is not present in every agricultural organization we partner with, certainly the foundations of FSA that include simple plot trials and field surveys are present (Table 1). These types of research methods are very reliable and support the reductionist approach to science research. However, FSA usually involves some aspect of trying to understand complexity and trade-offs which requires a significant shift in skills and approach to research design. The emphasis must be put on appreciating when an FSA approach is needed and training a limited number of researchers to be able to conduct analyses. Soft skills associated with collaboration across disciplines and working within a multi-disciplinary team are equally as important as hard technical modelling skills. Some reports do explicitly note that training is required in FSA. For example, SRA/2016/051 recommended that short course in farming systems research should be established at YAU (Myanmar).

The degree of capacity of Australian agricultural scientists to conduct FSA is dependent on the degree of multi-disciplinary approaches and systems thinking already being used in the research organization. For example, if modelling capacity is separated from biophysical and social science capacity at an organizational level this can limit synergies between scientists. In a survey conducted in 1985 Australian scientists in the plant and animal sciences felt their role in a project was to find and test solutions to a problem once identified, whereas the social scientists focused on problem diagnosis and had relatively little involvement in solution design, testing and verification (Fig. 4, Remenyi & Coxhead 1985). Hopefully the perspectives of scientists today are different, however there are still academic and institutional barriers to scientists who employ broad approaches to agricultural problem solving being fully recognized.

It is not necessary for Australian organizations to supply all the capacity needs in relation to an FSA, and arguably the best approach would be for each partner on the project to be contributing different skills and capacity to address the research questions. There is also a realization of the impact of the conceptual frameworks that often implicitly adopted by researchers in various disciplines but can shape how we address agricultural problems (Foran et al. 2014).

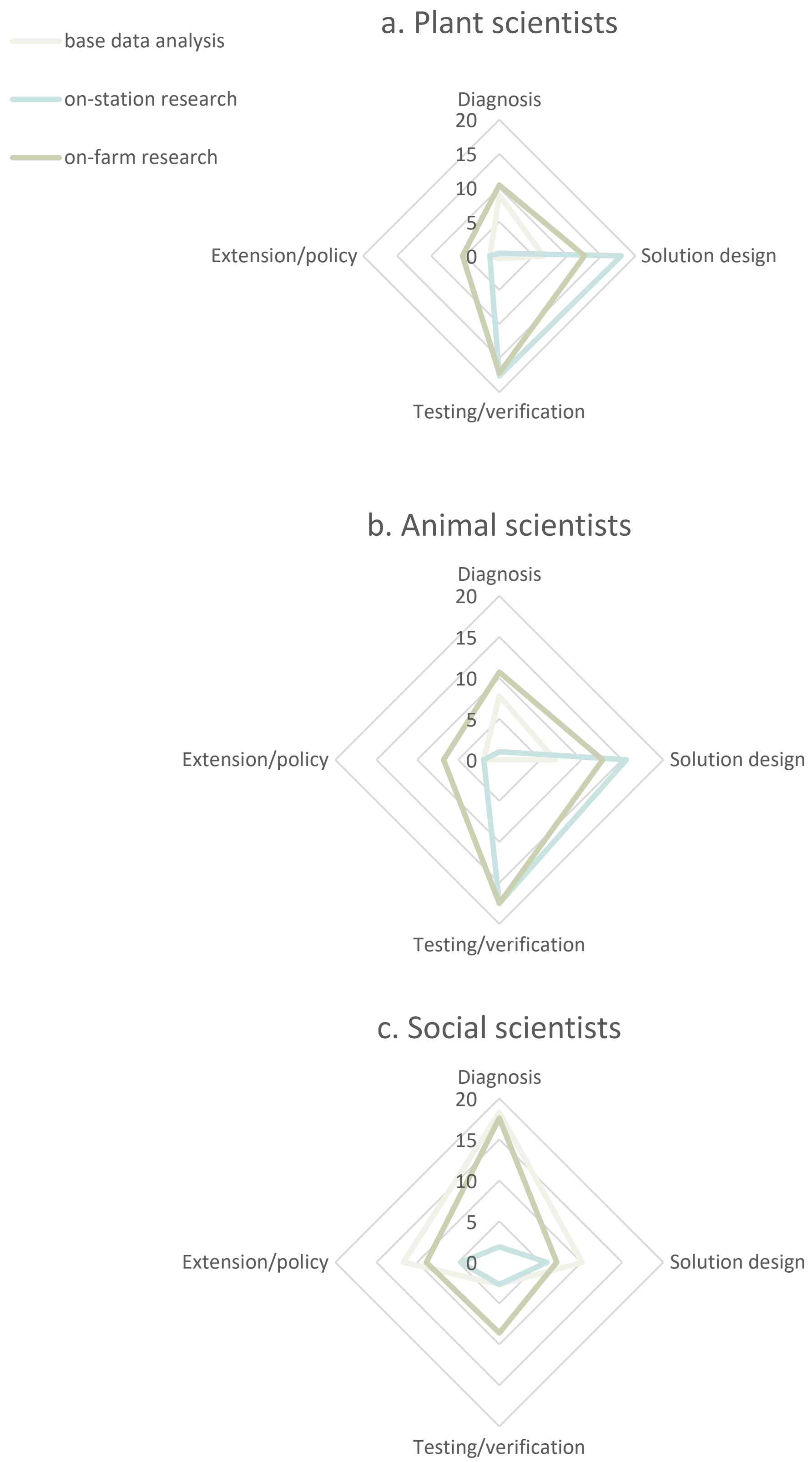

Figure 4. Survey of 181 Australian researchers conducted in 1985, showing their interest (as a percentage) in different areas of farming systems research. From plant sciences there was 279 entries, animal science 103 entries, and social science 257 entries. Adapted from Remenyi & Coxhead 1985, Table 7.

Summary and strengths of ACIAR

FSA is not a novel concept to the research teams involved in ACIAR projects, and many ACIAR projects already involve multi-disciplinary teams and often address complex problems. Therefore, further development of a strategic approach to FSA in the context of ACIAR objectives is feasible. ACIAR funded research does articulate and describe the needs of smallholder farmers in a comprehensive manner. This information could be used to ensure that FSA-derived products address their needs. Therefore, this research could be used as a valuable input into model or platform development, and the development of tools for decision-making by farmers. Finally, ACIAR can help to develop links between the pre-competitive space of model and data development and the competitive space of knowledge product development. As a research broker ACIAR is a good position to facilitate linkages between holders of private and public data (Antle et al. 2017) and ensure the research delivers benefits for smallholder farmers.

Focal areas identified

Given the stock take conducted the four focal areas identified that should be addressed in the next three years are:

1. The use of FSA to address the sustainability of alternative farming systems, especially those that are seeking to intensify or diversify. Given the long-time scales involved in addressing sustainability, an FSA approach could be used more frequently. Whilst other partners are developing sustainability indicators, ACIARs focus should be on using these indicators to predict the impacts of alternative farming systems on natural resources and the health of farming communities, with a goal to developing strategies to mitigate negative impacts of intensification or diversification.

2. Further integration of FSA with value chain analysis and food production systems. Currently, most FSA research is focused on the geographic unit of the farm. However, methods to integrate farm inputs and outputs, and links with food processors, into a systems framework are required for addressing some of the constraints associated with adoption of new farming systems.

3. Development of approaches to using FSA to help address research questions associated with strategies for scaling up and out agricultural innovations in different contexts. Determining the most efficient way to extrapolate the findings of small plot trials and isolated case studies to new geographies and contexts could be achieved using FSA. This research would facilitate the development of cost-effective and appropriate scaling strategies (and in some cases inform 4).

4. The impact pathways for FSA research in relation to ACIAR objectives are still unclear. When and how the research findings from FSA can be used by smallholder farmers to improve farm sustainability, livelihoods, and reduce poverty is not consistently described in proposals. These pathways need to be better articulated in project proposals and important collaborations to extend FSA findings beyond the scientific community need to be recognized earlier in the project cycle.

Consultation with scientists and their feedback

A period of consultation with relevant scientists was undertaken from June to August 2019. This involved sending out a request for feedback via an email to 42 researchers in Australia and overseas. It included people from CG centers, Universities, and government research organisations. Whilst there was a good mix of people from different scientific disciplines, the social sciences were the least well represented. People were provided with the stocktake document and asked to comment on the four focal areas via an online survey. Some people also provided feedback via a conversation over the phone. Below I summarize their thoughts and ideas.

The scientists perceived that the adoption of FSA approaches in projects related often to the complexity of the problems being addressed in the project and the magnitude of the financial investment (i.e. larger projects often required an FSA approach as they address larger problems). Among smaller projects, with more focused problem areas, the main research approach has been discipline-based. It was acknowledged that the complexity of smallholder systems is sometimes very high. One researcher noted that in the context in which they work one farm may have 10 crop species, 5 permanent tree species, 3-4 animal species all needing some level of attention or management decisions. Therefore, they were pessimistic about the ability of any FSA to encompass this complexity in a meaningful way. Conversely, it was appreciated that a complex system does not necessarily require the use of complex models, and technical complexity does not always equate to improved predictive performance of models (Keating & Thorburn 2018).

Project managers acknowledged that finding scientists that have both a systems understanding and facilitation skills to integrate across disciplines is challenging. Therefore, it isn’t surprising that most projects are conceived, developed and managed by disciplinary focused researchers, and therefore tend to follow a reductionist paradigm of science. The skills to encourage participation and transdisciplinary research are not always present. There was a perception that FSA has been the focus of crop or farming systems modelers (with relatively minor additions from social and economic science disciplines). The desire to encompass the broader definition of FSA (i.e. integration of biophysical and socio-economic perspectives, approaches and data) is present. There was an acknowledgment that social system knowledge is important if you want to change a system.

All four focal areas scored high in terms of importance (Fig. 5, all >5). However, some people did consider the FSA is and should be focussed on the farm unit and therefore focal area 2 was less important. Conversely, others thought the framing of focal area 2 was too constrained by the use of value chain analysis and should encompass agribusiness concepts, and the farm household. Asking respondents to rank the focal areas relative to each other was challenging. This is reflected in the quantitative results which show that no single area was ranked high or low (Table 4) and two respondents chose not to complete the task. Some people commented that they consider all these areas important, therefore couldn’t rank them in a relative sense.

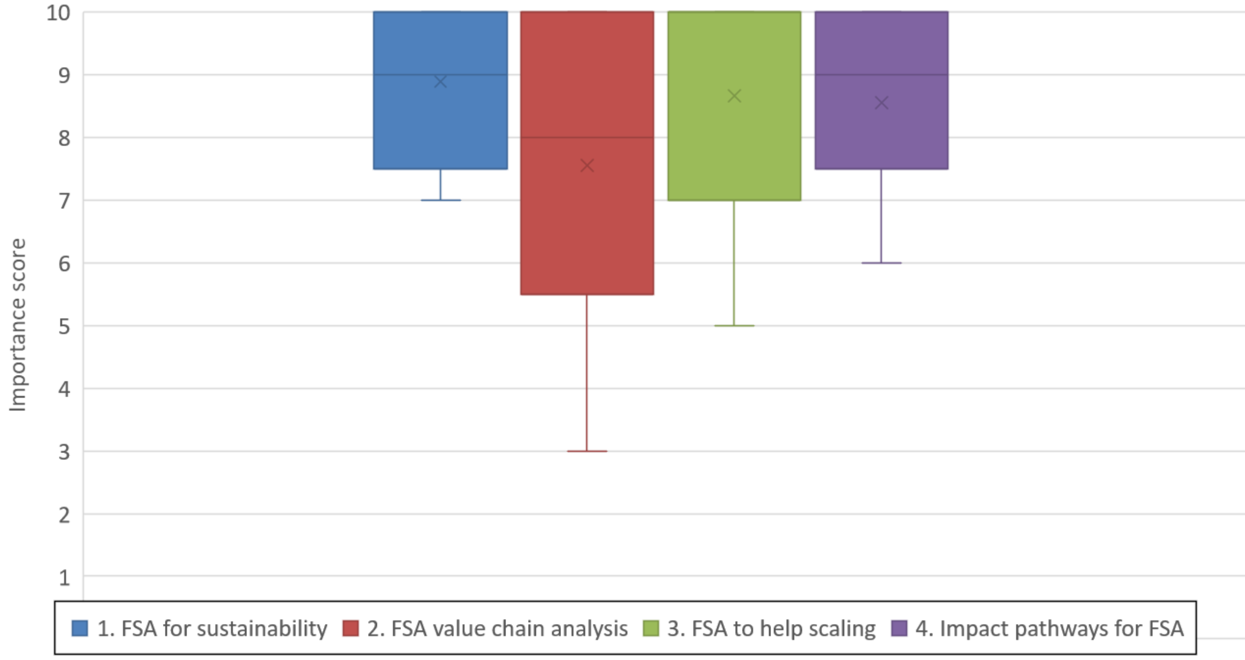

Fig. 5. *Boxplot of the independent scoring of the importance of the four focal areas from the respondent's perspective. From 10 being very important, 5 being somewhat important and zero being unimportant. Boxplot based on 9 responses.*

Table 4. *Relative ranking of the four focal areas from most important to least important from the respondent's perspective. Based on 9 responses.*

	res1	res2	res3	res4	res5	res6	res7	res8&9	mean rank
1. FSA to understand sustainability	2	3	1	2	4	1	3	NA	2.3
2. FSA and value chain analysis	4	2	4	3	1	2	4	NA	2.9
3. FSA to help scaling	1	1	2	1	2	4	2	NA	1.9
4. Impact pathways for FSA	3	4	3	4	3	3	1	NA	3.0

1. FSA to understand sustainability

Whilst there was agreement about the use of FSA to address the concept of sustainability in a research context, solely focussing on sustainability as an outcome of system change was seen as too narrow. A systems approach that maximizes the efficiency and use of was multiple resources (e.g. labour, land, nutrients, and water) was emphasized. If the goal is to intensify or diversify in a sustainable way we need to consider the agribusiness system that the farm sits within as well. Focussing on the adoption of a single intervention was not going to address the complex issues of poverty and food security. The non-farm parts of the chain may impact the sustainability of alternative farming systems or constrain changes to farming systems. This is especially true in the context of smallholder farmers who may struggle to find markets for their products.

2. FSA and value chain analysis

The statement that currently most FSA research is focused on the geographic unit of the farm and expanding this view may be beneficial was not disputed by the scientists. However, the narrow definition of the value chain was not supported. A farming system is embedded in an agri-food system of which value chains are an important component, but not the only component. The growing demand for food that has some degree of processing by consumers means that the middle part of the value chain is becoming more important in developed and developing countries. This shift towards farmers understanding and responding to consumer demands raises new research questions:

- Do farmers know how to collaborate to market their products?
- Do farmers have access to reliable, useful feedback on their products from consumers to make better on-farm decisions?
- Are farmers' supply networks sufficiently trustworthy to make collaboration a reality?

The second area of re-framing was around the farm household (as distinct from the geographic farm) as the central feature in FSA. The reasoning here is that unless an intervention works for the household they are unlikely to be adopted, and most of the interventions we assess are aimed at improving the well-being of the farming household whilst meeting other environmental or sustainability goals. An activity (or multiple activities) that gather household survey data are not unusual in ACIAR projects, so this is more about integrating this data and using it in a broader systems context. A detailed example of this is seen in Wilkus et al. (2019), but there may be simpler ways of achieving this as well.

3. FSA to help scaling

The decisions around extending some agricultural innovations are often made at the end of a research project. Planning for scaling (and the extension processes implicit in this) need to be considered from the start of a project. Currently, this is not really viewed as part of the "research" process and this means important stakeholders are not engaged early in the project. The lack of a functioning agribusiness system can be a critical road black to development activities (this also relates to focal area two).

4. Impact pathways for FSA

Whilst many of the respondents agreed that impact pathways for FSA research need to be articulated in a clear way there was mention of the constant debate around the role of ACIAR as a research broker and pushing of boundaries into extension and scaling of innovations. Extension stakeholders in particular need to be involved at the start of research projects, not only at the end if impact pathways are to be considered properly.

Areas missed in my assessment

We should prioritize conceptual modelling, not just quantitative crop or farm modelling. This would enable greater engagement by scientists from social and economic backgrounds, and therefore contribute to a truly trans-disciplinary research team. Given the shift to more user-friendly crop and farming system modelling tools (i.e. we can now invest more in using models versus developing models) this is possible within a project life-cycle (Keating & Thorburn 2018). In addition, this shift could encourage the incorporation of new information. For example, farm workforce and labor dynamics information as linked to changes in the social organization of farm households and communities represent important production constraints in certain farming systems.

It is important to consider a shift to a dynamic approach to farming systems research. This involves studying how the system has changed in the past and may change in the future, rather than a description of a farming system in a static state. This may assist in the development of adaptive approaches to overcoming production constraints (Schiere et al. 2012).

The use of FSA in a participatory learning exercises with farmers and extension people was overlooked in my analysis. There has been some success in Australia using this approach to help researchers, farmers and advisors all understand how the system works, and identify common leverage points and constraints for different stakeholders (McCown et al. 2009, 2012). The use of this in the smallholder farmer context is less clear and deserves some analysis. There were some comments about FSA to help develop decision support tools for intermediaries such as agronomic advisors and extension staff (see discussion about farmers' decision support systems in McCown 2002). There may be certain contexts where this output would be a valuable legacy from a research project, being mindful that decision support tools are usually used for a short period of time but are important during that time period.

Recommended strategy for FSA in future ACIAR investments

In response to the feedback received, the focal areas have been revised to:

The use of FSA to address the sustainability of alternative farming systems, especially those that are seeking to intensify or diversify. The dynamics of farming systems undergoing change need to be understood within a sustainability context. Given the long-time scales involved in addressing sustainability, an FSA approach could be used more frequently. Whilst other partners are developing sustainability indicators, ACIARs focus should be on using these indicators to predict the impacts of alternative farming systems on natural resources and the health of farming communities, with a goal to developing strategies to mitigate negative impacts of intensification or diversification.

Further development of FSA that includes interactions between the farm household and the broader food production system. Currently, most FSA research is focused on the geographic unit of the farm. However, methods to integrate farm inputs and outputs, and links with food processors, into a systems framework are required for addressing some of the constraints associated with adoption of new farming systems. The emphasis should be on if and how interventions build social and economic resilience in the farm household and allow smallholders to access markets that value their production practices.

Development of approaches to use FSA to help address research questions associated with strategies for scaling up and out agricultural innovations in different contexts. Determining the most efficient way to extrapolate the findings of small plot trials and isolated case studies to new geographies and contexts could be achieved using FSA. This research would facilitate the development of cost-effective and appropriate scaling strategies and highlight who needs to be involved with the project from the start. These scaling strategies should be linked to the impact pathways, and theory of change described in the project proposal, therefore this work should take place during an SRA, or at the very early stage of a project.

My recommendation is for ACIAR about to **implement activities or research projects to address these three focal areas in the coming years**. In the near future ACIAR should facilitate the development of an FSA platform with three components:

A collection of well-developed farming systems analysis tools that are useful in the smallholder context. This would include tools and approaches that are practical for smaller research investments, but scaleable for larger investments. The focus should be on the use of tools by stakeholders, rather than the development of new or more detailed tools. Methods for integrating household data and value chain data with the biophysical data are currently poorly developed. Examples include ADOPT for smallholders, Brown et al. 2016, Kuehne et al. (2017) workshop FARMSCAPE (McCown et al. 2009, 2012), IAT Integrated Analysis Tool (McDonald et al. 2019), CLEM, and Dry Arc initiative tools, ICARDA and other CG centers, fuzzy cognitive mapping using mental modeler software, Interactive Multiple Goal Linear Programming (SIAGI), bio-economic models and many others.

A knowledge bank that describes how these tools can be used in a research project. Ideally to help with pre-project scenario analysis to develop scaling strategies, or to engage stakeholders in aspects of the research, help teams think about new ways of conducting research, and integrate all the data collected during the project for use.

A community of practice that brings scientists together to further develop FSA in R4D research. Ideally this would contain a diversity of scientists at different stages in their career and from different organizations who are able to deliver to projects. There should be a focus on integrated modelling skills development.

In the short-term I suggest that **ACIAR funds, plans and conducts a two day workshop** with the aim of bringing a core group of scientists together to explore the three components above. Ideally this would take place in early 2020 and would involve a tools stocktake (day 1) and the then a case study example (day 2). An ideal case study would be a 10 year program that is currently under development for salinity management in Pakistan (preliminary proposal due to IHR Dec. 2019, "living with salinity") which would make an ideal case study to focus the efforts of the group on the second day. The project will involve firstly, a high level spatial overview of the degree of the salinity problem across Pakistan, and secondly examples of farm-level interventions that have proved beneficial in addressing this problem. The workshop participants could answer two questions:

Which FSA tools and approaches would be useful for describing the scale and magnitude of the salinity problem in Pakistan (given the data requirements etc.)?

Which FSA tools could be used as a framework for assessing the scalability of likely interventions?

This would strictly be used as a case study and does not dictate the use of certain approaches in the project design itself, it would be used only as a practical exercise for the workshop participants. However, some useful further work may come out of the activity. At this stage I would target the workshop participants to include the PL of the salinity project and key scientists from the recently completed SIMLESA project (CSE/2013/008), the SRSFI (CSE/2011/077) project in its final phase, and the SIAGI project (LWR/2014/072). With the addition of people who have used IAT in past projects.

Outputs from this workshop would also include a list of tools at various stages of development and use, and I would like to develop this into a **living guidebook for researchers wanting to conduct FSA** (ideally hosted on ACIARs website or an independent website and updated yearly). A decision may then be made to further develop certain tools into more user-friendly interfaces and/or implement the use certain tools in a research project context**. An SRA be developed to conduct any tool development activities, conduct training of project staff, or to further explore the usefulness of certain tools to address specific research questions.**

I recommend that project proposals being developed for the concept note round of early 2020 (for commissioning in 2020/21) have a renewed focus on the use of FSA to address research questions. I'm not sure yet how to operationalize this in the concept note assessment process, however I think this needs to take place at this early stage rather than at the preliminary proposal stage.

I recommend the commissioning of an SRA or research project that addresses the issue of "sustainable intensification" in research projects. We have several projects in this area, yet the concept of sustainability is often poorly explored in the smallholder context. I recommend a project to directly address this challenge using an FSA approach (either across projects or focused on one region).

Conclusions

It was clear from the many passionate scientists that I spoke to during this exercise that they all see an important role for ACIAR in facilitating multi-disciplinary research to solve agricultural problems. It was noted that developing countries face multiple constraints and problems that are unlikely to be solved with disciplinary projects that aim to solve single constraints. Therefore, there is a need for system approaches that seek to maximise the efficiency in the use of multiple limited resources. The researchers were familiar with the constant debate within ACIAR between committing resources to address research questions versus resources to extension and scaling of technology or practices. However, all acknowledged the importance of both for creating real impact. To summarise there were three areas where FSA could make a greater contribution in the future:

- FSA can encourage researchers to think about the inter-connectedness of the system they are trying to understand (regardless of their disciplinary backgrounds),
- FSA can help researchers change they way they design agricultural research projects (from simple factorial experiments to more complex designs involving different sources of knowledge),
- FSA can support and foster collaboration between scientists, extension staff and policy makers who are all part of solving agricultural problems.

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Appendix 1. Current or recently completed ACIAR projects that include components of farming system analysis (FSA).

**FSA code; 1 = FSA explicit in proposal and some integration across components, 2, FSA present but implicit, 3 project has components of FSA but little integration (at the proposal stage).*

FSA code*	Project code	Title	FSA
1	CSE/2013/008 SIMLESA I and II	Sustainable Intensification of Maize-legume cropping systems for food security in Eastern and Southern Africa	Intensification in maize-legume crop rotations, residue management. See case study box. 1. Created a very large data set to feed into bio-economic models to understand the benefits of conservation agriculture adoption. Rodriguez et al. 2017, household surveys linked with a dynamic whole farm simulation model, to examine trade-ffs in relation to crop residues. Baudron et al. 2015, Crop-livestock interaction model at farm-scale, again for crop-residue management in Zimbabwe. FSA explicit in this project.
1	LWR/2014/072	Promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh	This project uses an interdisciplinary systems approach that integrates social, institutional and biophysical research methods. Integrated modelling framework to explore water-related trajectories of agricultural intensification and their impact on social inclusivity and equity. Project uses the Integrated Assessment Modelling process, see figure 6 and 7 in proposal document. This includes a scenario based bioeconomic discussion tool and fuzzy cognitive mapping.
1	LWR/2014/073	Cropping systems intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India	This project combines modelling at the polder level of water and salt dynamics with modelling at the field plot level of options for crop and water management. The modelling will be complemented by field testing of options to make better use of residual soil moisture at the end of the monsoon, increase water productivity, limit waterlogging and salinity on crops, and evaluate technologies for intensification. Economic analyses of options to ensure financial viability also included. Some degree of integration using the APSIM modelling platform.
1	HORT/2014/096	Enterprise-driven transformation of family cocoa production in East Sepik, Madang, New Ireland and Chimbu Provinces of Papua New Guinea	Evaluate on farms, with farmer participation led by village extension workers, options for development of new cocoa farming systems integrating food crops, livestock, and high-value shade and other tree crops. The project will increase understanding of the benefits and problems of intensified production on small, lightly shaded cocoa trees and of diversification with food crops, valuable shade trees and livestock. It will lead to a more whole-systems approach to studying improvement of livelihoods on cocoa farms. RQ; what are the most productive systems for combining cocoa growing and food cropping in the various regions? VEWs will conduct surveys and interviews to assess the adoption and

FSA code*	Project code	Title	FSA
			outcomes of integrated cocoa farming systems. On-farm trials rather than models used, but FSA explicit in proposed methods.
3	SMCN/2012/075	Management practices for profitable crop-livestock systems in Cambodia and Lao PDR	Database of water, soil, nutrients at crop/forage sites, used to identify options to integrate, and biophysical constraints on biomass production.
-	SRA/2016/051	Cropping systems and integrated nutrient management in the central dry zone of Myanmar	Synthesis of previous investments in Myanmar, recommendations for future RD&E. "The likelihood of multiple production constraints combined with lack of capacity to conduct agronomic research means that there is an urgent need for multi-factor farming systems experimentation in the CDZ. We propose that a whole farming systems approach that addresses multiple issues simultaneously could lead to a step change in production and profitability in the CDZ." p26.
3	ASEM/2010/049	Market-focused integrated crop and livestock enterprises for NW Cambodia	Project will collect social, environmental and economic (triple bottom line) baseline data for upland farming systems with respect to the potential for development of integrated crop-cattle enterprises. They aim to identify of farming systems options that will delay or prevent the degradation of soil and natural resources for farming systems in NW Cambodia.
3	SMCN/2011/047 MyPulses	Increasing productivity of legume-based farming systems in the central dry zone of Myanmar	Multidisciplinary research on legume-based farming systems in Myanmar. Improved nutrient management of the legume-based farming systems focussing on the supply of phosphorus, nitrogen, boron, sulphur, potassium and zinc, and including legume inoculants. The team will incorporate, where appropriate, outcomes of the crop selection, pest, disease and nutrient management themes in the farming systems experiments.
2	FIS/2016/135	Development of rice fish systems in the Ayeyarwady Delta, Myanmar	Research to characterise and map rice-fish systems (RFS) in the Ayeyarwady delta. Trials to identify improvements in RFS and management that optimise gender-equitable income, food and nutritional outcomes. Analysis of cropping calendars for optimizing productivity, water availability and profitability outcomes. Analysis of social, gender economic production and environmental outcomes from RFS improvements.
3	HORT/2016/190	Improving mango crop management in Cambodia, the Philippines and Australia	Some research on how the technology transfer system operates and identified what could be done to improve the system. Focus on the extension system.

FSA code*	Project code	Title	FSA
		to meet market expectations	
3	HORT/2016/188	Developing vegetable value chains to meet evolving market expectations in the Philippines	Developed and tested a scalable GAP system. Characterised the vegetable production and distribution system.
3	HORT/2014/094	Developing the cocoa value chain in Bougainville	In collaboration with the TADEP "Umbrella project" we will develop survey tools to collect baseline information on cocoa-growing communities. Data will include geopolitical factors, economics, populations, livelihood strategies, housing standards, education, healthcare, access to mobile phones, banking, farm sizes and enterprises, details of cocoa activities, exposure to past training.
3	PC/2010/065	Integrated crop management strategies for root and tuber crops: strengthening national and regional capacities in Papua New Guinea, Fiji, Samoa, Solomon Islands and Tonga	What is the distribution of the two species of sweet potato weevil across countries and farming systems in the Pacific islands? What is the level of damage and crop loss associated with each species and in which localities and situations are the losses most severe? Integrated management components
3	HORT/2018/192 (preliminary proposal)	An Integrated Management Response to the spread of Fusarium wilt of Banana in south-east Asia	Previous research has identified that increasing diversity in cropping systems leads to an increase in soil biological diversity, which can suppress Fusarium wilt. The first objective focusses on answering the question whether intensification of the banana production system has changed the banana microbiome making it more conducive to wilt pathogens like Fusarium. Includes a field survey of different intensity banana production systems. Survey of grower networks and farm decision making. Development of a decision support tool.
3	HORT/2014/083	Developing improved crop protection options in support of intensification of sweetpotato production in Papua New Guinea	Evaluates 'best-bet' combinations of integrated pest and disease management (IPDM) options.

FSA code*	Project code	Title	FSA
3	HORT/2014/080	Integrating protected cropping systems into high value vegetable value chains in the Pacific and Australia	Develop and deliver recommendations for crop management in protected cropping systems. Evaluate selected high value crops and crop management practices, assessing quality, yield potential, pest incidence and disease tolerance/resistance. Analysis of value chain configurations involving protected cropping systems in Fiji, Samoa and Tonga to identify strengths and weaknesses.
-	CSE/2011/077	Sustainable and resilient farming systems intensification in the Eastern Gangetic Plains (SRFSI)	Understanding farmer circumstances with respect to cropping systems, natural and economic resources base, livelihood strategies, and capacity to bear risk and undertake technological innovation (obj 1). Farm typologies defined. Many on-farm trials implemented, especially in relation to conservation agriculture practices.
3	CIM/2014/082	Agricultural innovations for communities for intensified and sustainable farming systems in Timor-Leste (AI-Com)	This project aimed to understand and develop crop management packages to intensify annual rainfed cropping and increase the financial viability of maize, peanut, cassava and food legume producers. They also planned to develop ways to intensify irrigated cropping systems sustainably using limited spring-fed irrigation water. Most of the studies involved farmer participatory research (on-farm experiments), and them selecting innovations they would like to trial. Some APSIM simulation modelling and gross margin analysis.

Appendix 2. Organisations that have some FSA expertise or capacity

RICE flagship project 3: Sustainable farming systems

The CGIAR Research Program (CRP) on rice agri-food systems RICE, (2017-2022) is also known as the Global Rice Science Partnership. http://ricecrp.org/wp-content/uploads/2017/03/Flagship-project-3.pdf
Includes activities associated with FSA. "Farming systems analysis will be the entry point for identifying opportunities for diversification and intensification for improving farmers' livelihoods (e.g., crop rotation, opportunities for livestock or fish, and improved crop management)." Development of the sustainable rice platform (http://www.sustainablerice.org/) with a set of important indicators.

CIRAD Agroecology and sustainable intensification of annual crops

Has teams working on assessments of annual cropping systems, genotype by environment research, and agro-ecological engineering systems design team. Focus is more on agro-ecological than social.

Kansas State University Collaborative Research on Sustainable Intensification

The Feed the Future innovation lab for collaborative research on sustainable intensification. Developed a sustainable intensification assessment framework and toolkit.

PNG National Agricultural Research Institute

The Programme 'Agricultural Systems' represents the core business of NARI's AR4D efforts. This programme addresses the productivity of crops and livestock, production constraints and opportunities in the many Agriculture Production Systems across PNG.

PNG National Agricultural Research Institute

http://www.nari.org.pg/agriculture-systems-improvement

The Programme **'Agricultural Systems'** represents the core business of NARI's AR4D efforts. This programme addresses the productivity of crops and livestock, production constraints and opportunities in the many Agriculture Production Systems across PNG.