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Contributions to improved Food, Energy and Water security for sustainable food systems

A synthesis of results from the Sustainable and Resilient Farming Systems Intensification project to guide future investments

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In the interests of brevity and simplicity, individual sources are mostly not referenced, but are provided in the reading list in Section 9. Thanks also go to the SRFSI team members Mahesh Gathala, Avinash Kishore and Peter Brown who reviewed early drafts and improved the report.

OUR PARTNERS

EXECUTIVE SUMMARY

The nexus between food, energy and water is of critical importance to sustainable development, and managing these interactions at different scales is crucial if we are to achieve and maintain sustainable food systems. These issues are highlighted in the Eastern Gangetic Plains of India, Nepal and Bangladesh, where some 300 million people live amidst the world's highest concentration of rural poverty, and food insecurity is exacerbated by a strong dependence on agriculture, competition for energy and water resources, and climate change. Methods are needed that can address issues of food security and which also contribute positively to environmental and social outcomes.

The Sustainable Development Investment Portfolio (SDIP) is an Australian Government initiative, coordinated by the Department of Foreign Affairs and Trade (DFAT). It aims to improve the integrated management of food, energy and water in South Asia, to facilitate economic growth and improve the livelihoods of the poor and vulnerable, particularly women and girls. ACIAR's contribution to the first phase of investment (SDIP1) focused on understanding the bio-physical and socioeconomic settings in the EGP and improving the productivity, livelihoods and resilience of smallholder farmers to climate variability by facilitating the adoption of gender-inclusive, productive, profitable and lower-risk farming systems by over 75,000 farmers in the EGP. This project was delivered through the Sustainable and Resilient Farming Systems Intensification (SRFSI) project, led by the International Centre for Maize and Wheat Improvement (CIMMYT).

The farming systems improvements tested in SRFSI are based on Conservation Agriculture based Sustainable Intensification (CASI), which is a broader form of Conservation Agriculture that incorporates agronomic, socio economic and institutional aspects of food production, including more sustainable agroecosystem management, increased input use efficiency and increased biological and economic productivity. These are based on the CA principles of minimizing soil disturbance, ensuring soil cover and diversification through rotations – and include improved varieties, better irrigation practices and improved crop management techniques. Within the project, the four pillars of SRFSI are farmer participatory technology generation, local innovation systems which help overcome value chain bottlenecks, enhanced capacity of market and service agents to support farmer innovation, and farmer-to-farmer knowledge exchange. Extensive work was also undertaken in terms of understanding the local context from agro-ecological, socio-economic, institutional and policy angles. The research and development activities under the project were conducted in 40 nodes in eight districts across the EGP in Bangladesh, India and Nepal. These locations were chosen specifically to test techniques in a range of agro-ecological settings, as well as to enable cross-border comparison of results, and to explore the effects of institutional and policy settings.

Results from more than 3,000 participatory field trials demonstrated that CASI practices improved productivity and profitability while reducing water, energy use and labour requirements in rice, wheat, maize and lentil systems in the EGP. For CASI approaches to be implemented on a wide scale, farmers need access to the right machinery services, good quality inputs, affordable energy and water sources and assured market options, all available to them at critical times of the year. The project worked to improve the enabling environment through initiating and supporting multi-stakeholder groups called Innovation Platforms (IP), interaction with existing agencies, and capacity building of key local and regional stakeholders.

IP are groups of stakeholders that interact within an agricultural system to solve problems at the local level. The project has supported the operation of 34 IP across the three countries, which coordinated local stakeholders to address issues in input supply, access to machinery, marketing and cross-site learning. These IP have included the private sector, which has been key to accessing improved markets and services. Thus, adoption of CASI approaches by farmers also benefits local businesses and provides opportunities to expand services and incomes.

The participation of women ranged between 33% and 62% through the implementation of a deliberate and specific gender strategy. Women have additionally reported the key impacts of CASI being higher incomes, a reduction in farm labour use, lower labour and production costs, reduced drudgery, more time to do other productive tasks and for leisure, better education for children and better family nutrition. At an operational level, the project has been instrumental in increasing awareness and mainstreaming of gender inclusion among the SRFSI project and partner teams.

The use of CASI approaches increases resilience to climate change and climate variability through improved agricultural practices that improve resource-use efficiency and decrease vulnerability through exposure, sensitivity and adaptive management. It also results in financial, social, environmental and institutional sustainability by boosting incomes for farmers and local businesses; improving resource-use efficiency; and through the IP initiated as part of the project by strengthening connections between local stakeholders, and helping to remove barriers to implementation of CASI technologies.

Intensification of sustainable food systems requires policies and institutions that help smallholders minimize transaction costs and the potential risks involved in adopting new technologies and practices, and accessing markets. IFPRI a part of the SRFSI project team identified the major constraints to sustainable intensification, including small and fragmented landholdings; high cost of irrigation despite a relative abundance of groundwater; reliance on rental markets for machinery in a location where rental markets are underdeveloped or uncompetitive; poor access to markets; low and volatile returns from agriculture; and weak institutional settings for extension, credit and insurance. These constraints must be addressed at policy and institutional levels if sustainable food systems based on CASI approaches are to be scaled effectively.

This synthesis and review of the results of the extensive work undertaken within SDIP to date will help inform future directions for ACIAR's planned work in the context of sustainable food systems. This will help in translating the contributions already demonstrated at local scales to significantly improved food, energy and water security into broader policy-based decisions at state, national and regional levels. Follow up work under SDIP2 includes regional food systems Foresight and dialogue activities, which will strengthen understanding of longer term food systems changes, the implications for food, water and energy security and transformational opportunities. This will include work at regional and local levels, capitalizing on the baseline knowledge generated under SRFSI in terms of understanding local systems, and modeling longer term water and farming systems impacts. Policy and institutional analysis will be undertaken to understand institutional arrangements that govern information transfer, water management options and risk management. Follow up work will also include field level studies to build on work done under SRFSI and monitor soil health and integrated weed management for long term sustainability. All follow-on work will have a gender inclusive focus. In addition, studies will be undertaken to characterise the nature and trends in women's engagement in agriculture for meso level regions with the EGP, as well as the processes that drive the shifts in gendered employment patterns in agriculture, and the policy implications of these. Activities that work to improve access to mechanization for CASI technologies will also continue, recognizing this as a critical part of scaling.

Contents

1 Introduction

The nexus between food, water and energy is of critical importance to sustainable development. Managing the interactions between food, water and energy at different scales is crucial if we are to achieve and maintain sustainable food systems. Current food production systems are under pressure from many sources: the population explosion, environmental demands, increased competition for water from other sectors, physical water scarcity due to climate variability and a greater demand for biofuels and renewable energy among them. In the broader context, these pressures occur within complex bio-physical and socio-economic settings and have impacts on social, economic, ecological and political outcomes. Often decisions made with regard to the management of food, water or energy are not considered in relation to the other interlinked elements, and so perverse outcomes are experienced. For any given circumstance there may be synergies and/or conflicts between the sectors. This is true at a range of levels, from the field or farm through to community, policy and regional levels. We need ways to understand and manage the food-energy-water nexus at different scales, and to communicate these understandings to generate action for widespread transformation of sustainable food systems.

The Eastern Gangetic Plains (EGP) of Bangladesh, India and Nepal is home to 300 million people, with the world's highest concentration of rural poverty and a strong dependence on agriculture for food security and livelihoods. The EGP has the potential to become a major contributor to South Asian regional food security, but rice and wheat productivity remain low and diversification is limited because of poorly developed markets, sparse agricultural knowledge and service networks, and inadequate development of available water resources and sustainable production practices. Labor shortages are becoming more acute. These factors lead to smallholder vulnerability to climate and market risks that limit farmer and private sector investments in productivity-enhancing technologies. Options are needed to sustainably improve food systems in the region.

The Sustainable Development Investment Portfolio (SDIP) is an Australian Government initiative, coordinated by the Department of Foreign Affairs and Trade (DFAT). It aims to improve the integrated management of food, energy and water in South Asia, to facilitate economic growth and improve the livelihoods of the poor and vulnerable, particularly women and girls. ACIAR's contribution to the first phase of investment focused on understanding the bio-physical and socioeconomic settings in the EGP and improving the productivity, livelihoods and resilience of smallholder farmers to climate variability by facilitating the adoption of gender-inclusive, productive, profitable and lower-risk farming systems. This was delivered principally through the 'Sustainable and Resilient Farming Systems Intensification' (SRFSI) project within the Brahmaputra and Ganges Basins. The implementation of SRFSI was led by the International Maize and Wheat Improvement Center (CIMMYT) under the guidance of ACIAR. The SRFSI project started in 2012 and is now focusing on scaling the adoption of Conservation Agriculture based Sustainable Intensification (CASI) to wider networks of farmers in the region until June 2019. The SRFSI project addressed two research questions: would farm management practices based on the principles of conservation agriculture (CA) and the efficient use of water resources provide a foundation for increasing smallholder crop productivity and resilience; and would institutional innovations that strengthen adaptive capacity and link farmers to markets and support services enable both women and men farmers to continue to innovate in the face of climate and economic change? The research targets rice-based systems in eight districts across the three countries of the EGP.

In the current second phase (SDIP2), ACIAR's role has expanded to include aspects relating to sustainable food systems in the context of the food, energy and water nexus. Targeted outcomes include strengthened mechanisms for regional cooperation; critical knowledge being generated and used; and improving the enabling environment for institutions and policy. In the agricultural sector, this means building an improved understanding of the likely longer-term changes that can be expected in the region; better capacity for policy level decision making and implementation for food, energy and water security under uncertainty; and linking to field scale work on resilient and sustainable food systems to ensure impacts are considered at all levels.

SDIP2 will be delivered as part of a wider ACIAR Regional Program. This program will build on the knowledge and partnerships generated within SRFSI, as well as capitalise on existing information and networks from other ACIAR projects in the region. Together, this work aims to improve dialogue focused on understanding future pathways for sustainable food systems, building on effective institutional arrangements and removing key policy and technical constraints to the wider adoption of sustainable intensification approaches. This requires in depth knowledge of the technical, institutional, economic and market realities that underpin strategic policy dialogues at various administrative levels, situated within an overall framework of sustainable food systems, including future pathways, from South Asia regional, national, and local leaderships.

More than 75,000 households have tested CASI technologies in Phase 1 of the project on over 15,000 ha; this has occurred through direct testing with the project, as well as convergence and spillover effects. In two nodes in Bangladesh, farmers are so convinced by their experiences with zero-till establishment methods that they are now using this technique to plant all their maize this way. Capacity building at a range of levels has been impressive; more than 10,000 farmers and local service providers have participated in trainings on a range of topics, including CASI technologies, local service provision and business skills. A further 1,800 scientists and project staff have participated in more technical training sessions.

A synthesis and review of the results of the extensive work undertaken within SDIP to date can help to inform future directions for ACIAR's planned work in the context of sustainable food systems. This will help in translating the contributions already demonstrated at local scales to significantly improved food, energy and water security into broader policy-based decisions at state, national and regional levels. Identifying and filling gaps in knowledge will be critical, to contribute to planning and implementation of effective policies. By examining the work undertaken in SDIP1, it will be possible to identify the key enablers of and barriers to effective institutional and policy arrangements for long term sustainability of the region's food systems, as well as the gaps in critical knowledge that can be pursued under SDIP2.

2 Approach taken in SDIP Phase 1

The focus in SDIP1 has been at the farm and community levels, with the aim of understanding local systems and demonstrating the contribution of Conservation Agriculture based Sustainable Intensification approaches (together referred to as CASI) to smallholder farming systems, while at the same time ensuring that the enabling environment is present to support and scale out these technologies.

The CASI approach is a broader form of Conservation Agriculture (CA) that incorporates agronomic, socio economic and institutional aspects of food production, including more sustainable agroecosystem management, increased input use efficiency and increased biological and economic productivity. These are based on the CA principles of minimizing soil disturbance, ensuring soil cover and diversification through rotations – and include improved varieties, better irrigation practices and improved crop management techniques. The four pillars of SRFSI are farmer participatory technology generation, local innovation systems which help overcome value chain bottlenecks, enhanced capacity of market and service agents to support farmer innovation, and farmer-to-farmer knowledge exchange. Extensive work was also undertaken in terms of understanding the local context from agro-ecological, socio-economic, institutional and policy angles.

The research and development activities under the project were conducted in eight districts in the EGP: Rajshahi and Rangpur in Bangladesh; Malda and Coochbehar in West Bengal, and Purnea and Madhubani in Bihar, India; and Sunsari and Dhanusha in Nepal. These locations were chosen specifically to test techniques in a range of agro-ecological settings, as well as to enable cross-border comparison of results, and to explore the effects of institutional and policy settings. The project developed activities in five nodes (communities) in each of eight districts in the EGP (i.e. 40 locations in total) and then used these activities as training grounds for up-scaling of project methodologies and out-scaling of technologies.

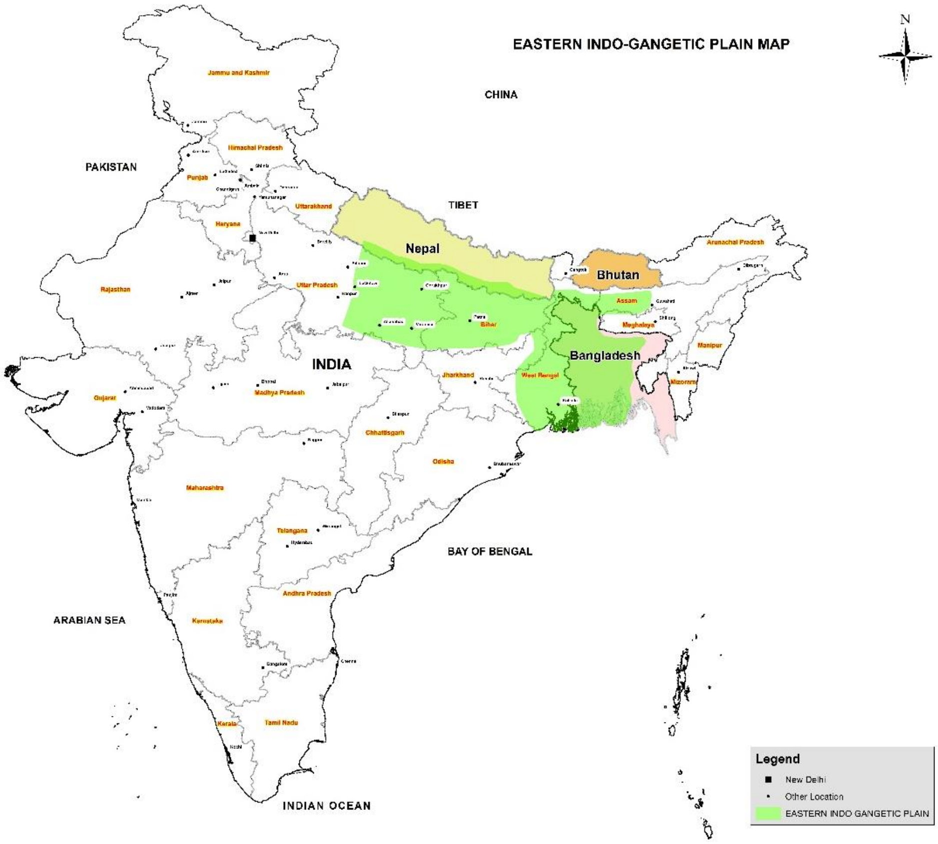

Figure 1 Project study sites in Phase 1.

Objective 1: Understand farmer circumstances with respect to cropping systems, natural and economic resources base, livelihood strategies, and capacity to bear risk and undertake technological innovation.

Rapid surveys and key informant interviews were conducted to characterize household and communities, including disaggregation for women-headed households where relevant. The exercise also described current farming systems, presence of input, output and service markets, water resources and water use, farmer-defined limitations to system productivity and motivations for intensification, and local strategies to deal with climatic variability and shocks. The appraisals identified representative communities for the establishment of on-farm trials and demonstrations, and further characterization studies were undertaken in these communities.

Flooding, surface water reserves and water table depth were monitored by NARES staff in all project communities during the first two years using methodologies defined with IWMI staff, to enable clear linkages with local water resource studies under a separate ACIAR project. The IWMI social science team took the lead in characterizing factors that govern access to irrigation along with bottlenecks and opportunities for expansion of irrigated area.

Farm typologies were defined and operationalized with input from CSIRO and eventually incorporated into formalized decision frameworks.

Objective 2: Develop, with farmers, more productive and sustainable technologies that are resilient to climate risks and profitable for smallholders.

Farmer participatory on-farm trials with CASI technologies comparing with farmers' practices (Conventional Tillage, CT), were conducted in several fields in each community and in each year, with more than 3,000 trials undertaken in total. Technologies concentrated initially on best-bet options resulting from studies and experience in adjacent regions: CA systems, direct seeding and unpuddled transplanting of rice, timely establishment of the winter crop, options for including a third crop after the main winter crop, intercropping (e.g. maize and leafy vegetables) and supplementary irrigation for both summer rice and winter crops. The technology 'menu' was guided by the initial surveys and participatory rural appraisals (Objective 1) and many of the potential technology options were not familiar to farmers in the target domains. Throughout the technology evaluation process, continuous farmer consultations guided the prioritization and adaptation requirements for different technological options to best match local conditions and evolved as farmer experience with different options matured.

Most trials were replicated in several fields within each community and were farmer-managed with backstopping from project staff and NARES partners. Where possible, collaborating farmers were selected by the community, and the project worked with existing farmer groups, including groups of both men and women farmers.

Other technologies tested include CA implements for both 2- and 4-wheel tractors, which underwent evaluation with the participation of machinery manufacturers, service providers and farmers in each district. Efficient pump technologies were quantitatively evaluated with NARES research partners.

The Agricultural Production Systems Simulator (APSIM) is an advanced simulation model for agricultural systems, and was applied to the study regions. The APSIM model was regionally validated using results from on-farm experiments and also secondary weather parameters. Validated models were used to explore the profitability, sustainability, and risk reduction potential of technological options under historical climate scenarios.

Soil data were monitored for changes in organic matter (organic carbon and nitrogen), pH, available nutrients and soil texture at the initiation of trials and at the end of the project. Using simulations of the effects of project technologies on key soil parameters over extended time periods with both historical and possible future weather data, the APSIM model was used to evaluate the long-term sustainability of technological options on the soils of the region.

Researcher-managed on-station learning module trials were conducted in selected districts to understand more about the technologies and to parameterise and validate the APSIM model. Such trials included: weed management in direct-seeded rice and rabi maize, and date of planting in rabi maize and wheat.

Objective 3: Catalyse, support, and evaluate institutional and policy changes that establish an enabling environment for the adoption of high-impact technologies from Objective 2.

Throughout the project targeted surveys, stakeholder consultations and FGDs were conducted to explore the technology preferences and decision-making processes of both men and women farmers and guide technology development activities along with companion interventions (e.g. training, access to credit and markets) that may foster innovation.

Decision support tools were used to prioritise high-impact technologies. Evaluations of efficiency, equity (including gender equity), sustainability and GHG emission balances were used to prioritise the technology options developed under Objective 2. Constraints to the adoption of promising technologies and their conditions of success were analysed by developing the socio-economic and agro-ecological typology of the potential target domains.

One of the major approaches to improving the enabling environment was to initiate new groups or strengthen existing entities called Innovation Platforms (IP) in each project district. IP are multi-stakeholder groups incorporating farmers and agents representing many of the principal components of the main agricultural value chains, who come together to address problems in their local systems. In many cases the project capitalized on existing groups and helped them build additional skills as required. These groups were used as sites for institutional learning, and to collectively solve problems within local farming systems. Through IPs, farmer awareness programs were organized, and mechanisms developed to link farmers with financial institutions and remunerative markets.

Service providers were a key to the adoption of CASI, and hence purchase of CA and irrigation equipment was given priority. Different service provider business models were evaluated for both efficiency and gender sensitivity. Support to service providers was provided both in the form of technical training and business development services in order to strengthen their ability to efficiently address the needs of different farmer groups, especially women farmers.

The project also explored different options for increasing the availability and accessibility of CA and irrigation equipment in the project areas, including aspects of local production, promoting opportunities to existing companies operating elsewhere, and availability of adapted equipment and credit for equipment purchase to strengthen entrepreneurship development. Backward integration for effective input delivery services were strengthened by harnessing the provisions of on-going government programs.

Existing policies, programs and institutions were evaluated for up-scaling the high-impact technologies that promote climate change adaptation and minimize externalities. The impact of promising technologies was quantified in an ex-ante framework and shared with research and development leaders and policy makers.

Objective 4. Facilitate widespread adoption of sustainable, resilient, and more profitable farming systems.

This objective has been addressed in two parts; within the main project delivery period, and in the current 'scaling' phase. In the main project research and delivery period, the project established field activities around five nodes in each of the eight districts across the EGP. Each community hosted technology evaluation sites, which also served as training and learning centres. Short training courses using farmer field sites as learning platforms were a key activity throughout the project. At the start of the project, all partners who were going to be involved in the management of project field activities participated in a course on farmer participatory research, innovation platforms, gender sensitivity, CA, supplementary irrigation, value chain and market development, seed technology and facilitation of farmer-to farmer knowledge exchange.

The project initiated ongoing opportunities for farmer knowledge sharing. Regular field days and focus group discussions (FGDs) in each season in each node or district allowed farmers from the areas surrounding the project communities to be exposed to the 'new' technologies and to have them explained in their own language by farmers themselves, capitalizing on farmer-to-farmer understanding.

Regular courses were offered for service providers and agro-dealers, helping form a network of project alumni that became the basis for further information and knowledge dissemination. Courses focused on project technologies, business development, and the role of farmer-to-farmer knowledge exchange for building demand.

The provision of essential machinery was first facilitated by the project in collaboration with the relevant local partners. A market development approach was used to encourage machinery manufacturers and distributors move into new markets in the target region.

In late 2017, the focus of the entire SRFSI project shifted to a 'scaling' period based on the successful techniques and approaches tested previously in the project. The scaling approach currently being implemented uses the concept of scaling 'ingredients' that must be present for wide scale adoption of any technique. In addition to the technology, scaling requires knowledge and skills, awareness and demand, monitoring and learning, leadership in scaling, partnerships, business models, value chains, financing and public-sector governance. The project is focusing investments on capacity enhancement pathways for scaling to improve the enabling environment for large-scale uptake of CASI innovations. This goes beyond merely scaling out of the trainings currently offered through the project and includes capacity building on other topics identified using the scaling ingredients concept. Based on the recognized needs, the commitment and resources of government and non-government scaling partners, and the expertise and resources available to the project team, the project is supporting scaling by targeting capacity development of agents of change at various levels of the local production systems.

Overarching theme: Gender

The project focused first on increasing participation of women in project activities, as well as understanding impacts on, issues for and preferences of women in the study areas. A range of strategies were employed to encourage skill development, help female farmers to become aware of modern farming techniques and bridge the gender gap in the SRFSI project's focus areas. Women and men were included in all SRFSI-organised activities, including training programs, field trials, exposure visits, workshops and data collection. A targeted approach was employed to ensure meaningful women participation. Focus Group Discussions (FGDs) were used regularly to capture both women and men's perceptions. Gender disaggregated data was collected and compiled on a routine basis. Reports showing gender disaggregated data provide analysts and policy makers with more gender sensitive tools with which to analyse and make policy decisions. A gender-sensitive data gathering protocol was developed for the socio-economic team to gather and record data. On-farm fieldwork was an opportunity for discussions with both male and female farmers. Female farmers include women who head the family, women in male-headed households and landless female agricultural labourers. These strategies and initiatives helped mainstream gender into the SRFSI project and reach some of the most marginalised sections of society, many of whom are women.

3 Understanding local systems

In Phase 1 the focus has been on understanding farmers' situations, including their operating environments and barriers to innovation. In conjunction with farmers and local stakeholders, project teams selected and tested sustainable and productive technologies for smallholders to improve resilience and profitability of their farming systems. At the same time, the project explored ways to support the enabling environment, including from a policy and institutional angle, to allow widespread adoption of the improved CASI farming systems tested by farmers. The deep engagement of communities, including farmers, service providers, and public and private entities has built trust and confidence between local stakeholders and the project team. The result has been a cohesive approach to testing relevant technologies, and at the same time creating conditions that allow farmers, including female farmers, to take advantage of these new techniques to improve their household food security and income.

The Food-Energy-Water nexus plays out at a range of scales, from the farm to community, state, national, basin and regional levels. Major farming system constraints of water (access, management) and labour are directly linked to energy through mechanisation, water pumping costs and water use (irrigation) and agri-inputs: an example of the food-energy-water nexus at the farm scale. At higher levels, policy decisions about water and energy development impact on household decisions. For example, development of water resources for hydropower affects the timing and amount of water available for irrigation, and energy infrastructure and pricing policy influence the way farmers access groundwater. The results from Phase 1 explored the ability of farming households and communities in the region to access resources, and demonstrated that food, energy and water security can be improved at the farm scale through use of CASI techniques. The necessary accompanying institutional and policy barriers and opportunities have been identified and require further work, particularly when considering the food-energy-water nexus at wider scales including community, district, state and regional levels. New trade-offs and opportunities will be evident as the research moves from farm to community, state, national and regional levels.

3.1 Farming systems

Agricultural systems in the EGP are dominated by a rain-fed rice crop in the kharif (monsoon) season, although it is possible for two kharif crops to be produced (i.e. kharif 1 and 2). The rain-fed kharif crop(s) are followed by an irrigated crop in the rabi (dry) season when farmers have access to irrigation or residual soil moisture. The main cropping systems differ by location, but are traditionally rice-rice and rice-wheat, with rice-maize a relatively new system in most areas. The kharif crop is central to household food security in a region where most farming households operate at subsistence level. CASI can improve productivity and profitability in the kharif season through the use of improved seed of appropriate varieties, mechanised crop establishment techniques for rice (mechanical transplanting and drill seeding), elimination of the traditional puddling operation, and better irrigation and fertilizer management.

Rabi crops in the study areas include wheat, maize, mustard, pulses (lentil, mung bean), jute and leafy vegetables depending on the location and water availability. Rice-wheat and rice-maize are the major cropping patterns. In Bangladesh, tobacco, potato and mustard are other important crops in the rabi season, while rice, maize, jute, vegetables and pulses are grown in kharif. In Bihar, vegetables and potato are planted in the rabi season, with rice, vegetables, maize, mung bean and jute in kharif. In West Bengal mustard, potato, summer rice, maize, pulses, tobacco are planted in the rabi season, with rice, jute, maize and vegetable in kharif. In Nepal, wheat, maize, lentils, vegetables and potato are planted in the rabi season, with rice, maize, mung bean and vegetables in kharif. The rabi season is where CASI approaches can potentially have the biggest impact in terms of water savings and increased profitability, and where opportunities for diversification are ecologically more feasible and more likely to be accepted by local communities.

Considering the entire cropping system as opposed to each singular crop is vital from a food-energy-water perspective, as there are residual effects (both positive and negative) from changes made in one season on subsequent crops. For example, minimizing or eliminating tillage and maintaining crop residue builds soil carbon and improves soil structure which improves water holding capacity of soil; fertilizer applied on a rabi maize crop often has a positive effect on the yield of the subsequent rice crop; planting pulses and legumes provides nitrogen for a following crop. From a FEW perspective, the biggest benefits from widescale implementation of CASI are likely to be through improved water use efficiency for rabi rice; the replacement of rabi rice with a lower water use and higher productivity crop like maize; expansion of rabi crop production through improved access and management of irrigation; and/or the ability to intensify with a third crop in between kharif and rabi seasons. All of these options improve water and energy efficiency at the farm level, while at the same time improving system productivity and profitability.

Cropping intensity is highly variable across the EGP, ranging from 180 – 247% at the district level. This is coupled with low productivity and limited diversification due to a range of interacting factors including limited market access; sparse agricultural knowledge and service networks; and inadequate development of water resources (whether due to physical infrastructure or economic barriers to pumping). Mechanisation is similarly limited to mostly diesel irrigation pumps, and 2- and 4-wheel tractors for farm operations. Thus, there is significant scope to improve the sustainable productivity of these systems.

3.2 Socio-economic settings

Across the study sites, common trends are observed in basic attributes such as land characteristics, social indicators (family size and structure), levels of food security, household income, and expenditure source and pattern (Aryal & Maharjan, 2015). However, this should not disguise the complexity of the socio-economic situation across the EGP in regard to the interacting factors of agro-ecological systems, livelihood strategies, farm sizes and tenure types, access to technologies and institutional environments which converge to create opportunities for improved sustainability.

Landholding size is small even by South Asian standards; average land size is just 0.6 ha, and this is often highly fragmented with as many as nine plots scattered in many places in some cases. Property rights are poorly defined in most parts of the region, including laws related to share cropping. Sharecroppers are registered in West Bengal, and therefore enjoy a somewhat better status. Most smallholders have food sufficiency for less than ten months, with a relatively high proportion food sufficient for less than six months, resulting in most farmers being marginal or subsistence level farmers. For example, 50 – 75% of farmers in West Bengal were classified as landless and marginal farmers.

The major share of household income comes from cereal production (rice and wheat), and income tends to be spent on food and farming. Access to markets is variable, with physical proximity to market sites ranging from 5 – 60km from the household. Some locations are linked to national markets via private sector initiatives, and in these locations farmers benefit greatly from these links.

Across the EGP farmers have very low levels of access to extension services, both formal and informal, and thus do not receive up to date information about improved practices. For example, around 12% of farmers in Bihar benefit from technical advice from government institutions, compared to 18% in Punjab. In West Bengal there is a history of successful Farmers Clubs, and a large number of these act as a local extension service for information and training, as well as providing custom hiring services for machinery.

Migration of male household members is a common strategy to diversify household income, and although the 'feminisation' of agriculture is not universal in the EGP, it is a notable trend in some parts, with the average incidence of female headed households ranging from 13 – 19% (Table 1). This requires attention to gender inclusion that enables women to have similar levels of access to critical resources as men (knowledge, finance, water, land) in order to boost productivity and profitability for female headed households. Within the household, women reported spending 50-60% of their time on household activities, with the remainder engaged in farming, livestock and leisure activities.

Table 1 Key socio-economic indicators of countries under study (Brown et al., 2017, pp 11).

Key indicators	Bangladesh	West Bengal	Bihar	Nepal
Average landholding (ha)	0.62	0.61	0.56	0.70
Female headed household (%)	13.5	19.2	17.8	12.7
Food sufficiency more than 10 months (%)	21.0	14.0	49.5	39.6
Income from cereal crop (%)	72.0	71.2	65.6	67.6
Income from non-cereal crop and other (%)	29.0	28.8	34.4	16.5

While the biophysical landscape is similar in terms of the extensive lowland alluvial plains, there are notable differences for example in soil quality which impact productivity. In Madhubani district (Bihar), soil acidity is a widespread problem that impacts on yield and farm profitability. Importantly from an intensification angle, access to irrigation is highly variable; even in the Nepal study sites, irrigation access ranged from almost 80% in upland areas of Sunsari to less than 20% in Dhanusha.

Access to credit is a long-standing issue within the EGP. Although there are financial institutions in all areas under the study, the ability of a farmer to access credit is highly variable. The rate of institutional loans for agriculture is 17% in Bihar compared to 49% in Punjab. In Bangladesh, accessing bank loans is a difficult process, and most smallholders rely on Micro Finance Institutions due to the ease of doing business, despite interest rates that are double those in banks. In Bihar and West Bengal, the presence of women's self-help groups and farmer's clubs is one way that access to credit has been improved for smallholder farmers. Additionally, in India, the introduction of the Kisan (Farmer) Credit Card Scheme allows easy access to credit from banks but can only be accessed by people who own land.

Due to limited public services in the EGP, most farmers depend almost entirely on the private sector to secure agricultural inputs and access markets for their farm produce. The EGP is a difficult environment for more formal medium and large-scale businesses; profitability is generally low, with farmers having small input requirements, low purchasing power and small marketable surplus. The cost of doing business with smallholder farmers is thus high for the private sector. Infrastructure is poor, and the region has low rates of urbanization and is distant from major urban markets and ports. Thus, the private sector in the EGP is dominated by small, informal and unorganized local businesses which have limited reach among consumers, and tend to provide un-innovative products and services using limited capital and adding little value. Such businesses can be inefficient, slow to adopt and promote new technologies, and have limited capacity to integrate smallholder agriculture with bigger markets to secure higher prices for farmers. However, the benefits are that they are able to serve even the smallest farmer, understand local systems well, and show a high degree of flexibility in serving those local systems. It makes sense to work to engage and develop the capacity of the small scale private sector, and various institutional approaches for collaboration have been explored which show that this sector can be effective in contributing to improving the sustainability of food systems in the region. This is explored in greater detail in Section 5.

These socio-economic factors interact with key climatic and biological constraints and result in low productivity across the region. Key constraints listed by farming households in the different project locations are listed in Table 2.

Table 2 Key production constraints (Brown et al., 2017, pp 14).

Location	Climatic	Biological	Socio-economic
Bangladesh	Drought, heat stress, rain, flood	Disease, pest and weed intensification	Non-availability of labour, machinery and skilled manpower for operating machinery; financial crunch.
Bihar	Drought, heat stress, flood, hailstorm	Disease, pest and weed intensification, quality degradation of soil	Non-availability of labour, irrigation, machinery, electricity, inputs and credit
West Bengal	Drought, heat stress, rain, flood	Disease, pest and weed intensification, ground water depletion	Non-availability of skilled manpower, machinery, quality inputs; difficulty in access to credit, market (input and output) and irrigation
Nepal	Drought, heat stress, erratic rainfall, hailstorm	Disease, pest and weed intensification, quality degradation of soil	Non-availability of inputs, labour, irrigation, credit, electricity; high prices of inputs; lack of access to services and technical know-how; poor marketing networks

3.3 Resource availability and accessibility – interactions between land, water and energy

Access to water resources for irrigation is essential for sustainable intensification of agricultural systems, and also highly dependent on simultaneous access to affordable energy where groundwater is utilized. Overall, the EGP differs from much of the rest of India, Nepal and Bangladesh in that rainfall is high, and water resources are under developed. Surface water is abundant in the summer monsoon, and scarce in the winter season. Even by South Asian standards, farm sizes in the EGP are low at around 0.6 ha per household. Fragmentation further impacts on efficiency and thus productivity. For these small landholdings, intensification is key to maximizing profitability. Future development in terms of diversification and intensification requires better access to more efficient use of more water, especially in the rabi season. In a groundwater dominated region like the EGP, access to affordable and sustainable energy resources is vital for increasing levels of irrigation.

Access to energy

Rural electrification is variable across the EGP and is not subsidized for agriculture as it is in many parts of South Asia. In Bangladesh, 56 – 70% of households in the nodes in Rangpur had access to electricity, although there was one node (village) with no access to electricity. In Rajshahi 68-88% households have access to electricity. No LPG gas was available in any node. All nodes in West Bengal have electricity connection. In Nepal access to electricity ranged from 83 – 100% in the study areas, but supply is highly irregular. In the IFPRI groundwater study, most households reported having access to electricity but there were differences in supply. West Bengal and Bangladesh have relatively reliable supply with households getting about 21 hours of electricity per day on average, compared to 10-11 hours in Nepal and Bihar. Therefore there are more electric pumps in West Bengal and Bangladesh. Solar power as a source for irrigation is currently used very sporadically in the EGP, and no farmers reported using solar powered pumps in surveys carried out within the project. However, solar pumps are being promoted as an alternative energy source that is reliable and has low operating costs.

Water availability

In accessing water for irrigation, there is an important distinction between availability (i.e. physical access) and accessibility (i.e. infrastructure and affordability). The International Water Management Institute (IWMI) conducted a temporal and spatial assessment of water available for irrigation in the eight districts of the SRFSI project (2015). They examined groundwater potential and surface water availability (including tanks and river). Groundwater potential for irrigation was based on the groundwater recharge and storage volumes within the limits of surface pumping systems, which have a limit of 9m below ground level (bgl).

Groundwater resources are underutilized in most of the project's study sites, and are not a constraint for irrigation. Most study districts show groundwater tables within 9m bgl, which means that small surface pumps can be used to access groundwater. The exceptions are parts of Dinajpur, Rangpur and Malda. Groundwater levels fluctuate on average by 0.49m in India, 0.36m in Bangladesh and 0.28m in Nepal on a seasonal basis, indicating heavier withdrawals in India followed by Bangladesh and Nepal. Temporal assessment of groundwater tables indicates significant hotspots of withdrawals that are likely associated with domestic and industrial activities. Apart from Dinajpur and Rangpur, these withdrawals are in isolated pockets.

There is an extensive network of temporary and permanent ponds in the region, but they are not commonly used for irrigation. River pumping is also not common, and surface water irrigation schemes are limited. Thus, surface water is a minor source of irrigation and does not offer an efficient strategy to support the expansion of irrigation in the short term, although may be developed in the longer term.

Apart from the project areas in Nepal, almost 90% of the study area is under cultivation for at least one season. Currently, continuous irrigation for three seasons ranges from 2% (Dinajpur) to 72% (Purnea), so there is scope to increase irrigation intensity given availability of water resources. To determine the potential for development of irrigation intensity, groundwater availability was linked to the optimal crop water requirements for the dominant cropping patterns in each district. AquaCrop was used to model three crop intensive irrigation patterns in all areas. The results show that there is a potential to use groundwater resources to irrigate between 57 – 188% of the total land areas within the study sites, based on using flood irrigation with application efficiency of 70%. Improvements to irrigation management, including the use of conservation agriculture could further increase the area irrigated.

Water accessibility

Although groundwater is readily available, access is variable in terms of affordability. In the EGP, over 90% of farmers rely on groundwater for irrigation, although there is some conjunctive use of groundwater and surface water from government canals in the Nepal sites. Most farmers have access to irrigation through private, informal rental markets. These markets play a major role in ensuring irrigation access for almost all farmers. In a survey conducted by IFPRI in 2015, 25% of farmers owned pump sets, and a further 75% rented pumps to access irrigation. Given the nature of landholdings in the region that are small and fragmented, access to irrigation through rental markets will continue to be important. However while access is almost universal, costs are high due to high diesel costs and low efficiency of diesel pumps in general. Water buyers, who are often smaller and poorer farmers, feel the high prices acutely. Most farmers practice deficit irrigation due to high pumping costs; this is evident because pump owners apply more water than renters. This has effects on yield and productivity for the whole system, since farmers are more likely to delay sowing of kharif rice as they wait for monsoon rains rather than irrigate. This in turn delays sowing of the subsequent rabi wheat crop, which then is more likely to suffer terminal heat stress later in the season, impacting on yields. Many farmers do not grow rabi crops due to the high costs of irrigation, despite a relative abundance of water and labour in relation to land availability.

While the number of pump sets has increased rapidly in the past 5-10 years and been coupled with increased efficiencies, irrigation costs continue to rise. Water markets have not responded to this increase in supply, and prices continue to rise disproportionately. Pump sets are most expensive in Nepal and cheapest in Bangladesh, a consequence of policies that restrict imports of agricultural equipment in Nepal and India. In Bangladesh where there are no restrictions on the import of cheap pump sets from China, the capital cost of pump sets is reduced, which has allowed more widespread ownership and competitive water markets.

Dependence on electric pumps is higher in WB and Bangladesh as electricity supply in those locations is more reliable. In other locations where electricity supply is more variable, there is more of a mix between electric and diesel pumps. Indeed, diesel prices are one of the main reasons given for high pumping charges across the region; because the variable costs associated with diesel pumps account for up to 90% of the operating cost, owners of diesel pumps choose to keep prices high and reduce the hours rented rather than lower prices and extend the hours of operation. This behavior appears to extend to pump renters who use electric pumps as well, despite lower pumping costs in general.

In considering policies to promote irrigation, subsidizing diesel pump sets does not benefit small and marginal farmers or tenant farmers, since pump owners on average do not maximise the time rented. These subsidies would be better targeted at smaller or tenant farmers who would seek to maximise the time rented. It is unlikely that prices for irrigation pumping will decrease until alternative – and cheaper- sources of energy are found for the EGP. This should be seen as an opportunity to reduce inequality in income from agriculture in a way that has not been possible with land reforms. Machine reforms could help to reduce inequality in income from agriculture, in a way that has not been possible with land reforms. Targeting machinery subsidies for landless or marginal farmers, and supporting rural youth to become service providers can increase incomes among small and marginal farmers.

High rates of groundwater utilization in northwest Bangladesh are due to concerted and integrated efforts and coordination on the part of the public and private sector, but in the Indian EGP and Nepal Terai groundwater is underutilized due to poor electricity supply, high diesel prices and uncompetitive groundwater markets. There is significant scope to develop sustainably intensified irrigation systems based on groundwater in these regions with the right institutional arrangements.

3.4 Farming systems zones for strategic development and scaling

The work undertaken within the project covered eight districts across four states and three countries, and is representative of the EGP. In total there are 180 districts within the boundaries of the region known as the EGP, covering 30 million hectares of land and home to some 450 million people. While we have described the general characteristics of the farming systems and socio-economic context within the study sites, there is also huge variability in the region in terms of social structure, farm types, cropping systems, land topography, crop yields, infrastructure, market networks, local policies and governance. Secondary data was used to characterize the region into six major farming system zones based on dominant cropping systems, crop yields, access to irrigation, availability of mechanization services, and livestock holdings (Figure 2). Cluster analysis was used to group zones, which were then mapped using QGIS software. Individual zones were then characterized for technological, policy interventions and estimated area for potential scaling. The scaling strategy for each zone will incorporate different technological interventions and policy recommendations based on existing biophysical, socio-economic, and institutional settings.

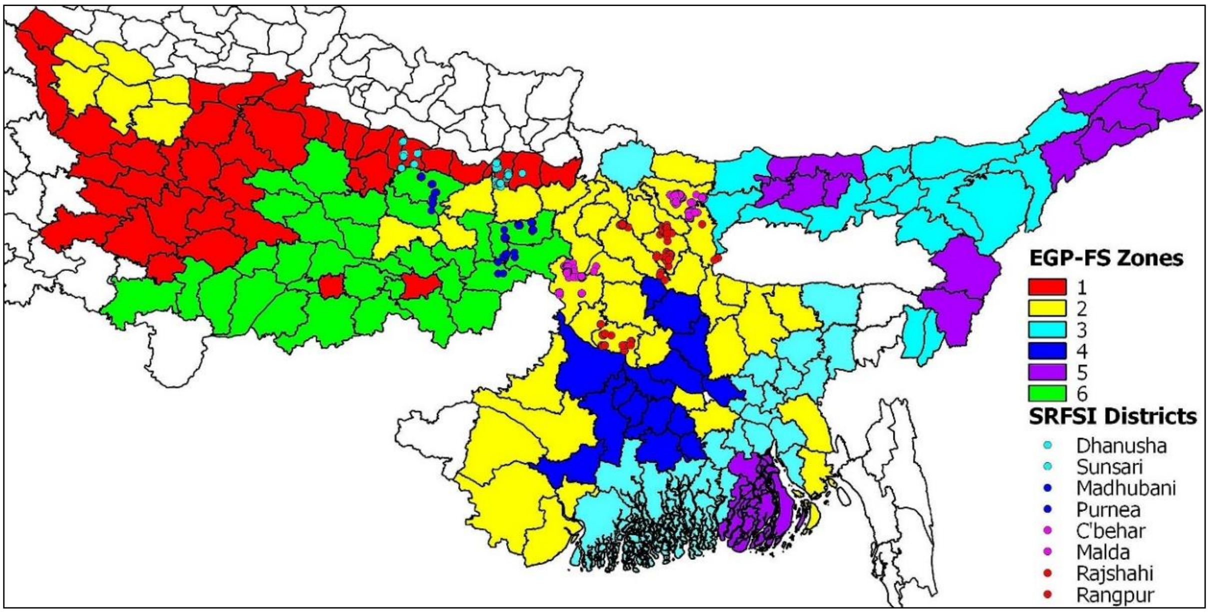

Figure 2 Farming systems zones in the EGP. SRFSI districts are represented by coloured points.

Zone 1

is dominated by rice-wheat cropping systems (54% of cropped area). The zone is characterized by poor soil and land management, poor road networks, a lack of availability of quality inputs and output markets, low intervention and thus poor adoption of modern technologies. Small and marginal farm households with fragmented landholdings make up 73% of farming households. Although there are high rates of irrigation (84% of cropping area), irrigation is costly due to a heavy reliance on diesel pumping. zone consists of 37 districts from Nepal, Eastern UP, and Bihar with a total cultivable area of 5.38 million ha. There is great scope for crop intensification by converting summer fallow provided that alternate irrigation infrastructure is developed to allow affordable access to groundwater (e.g. electrification, solar energy).

Zone 2

is dominated by rice-rice systems, with a cropping intensity of around 191%. This zone is characterized by high rates of small and marginal farmers (90% of households), low levels of access to irrigation (55% of cultivated area), good mechanization with 2- and 4-wheel tractors but poor local infrastructure for other machinery services, and poor value chain and marketing networks. The zone is highly vulnerable to climate change as there is a dependence on the monsoon rains for rice transplanting and up to 40% of the area is affected by flash flooding. This zone consists of 46 districts from Nepal, Eastern UP, Bangladesh and West Bengal, with the highest cultivable area of 8.67 million ha. There is a good presence of NGOs, and public and private sector actors, and thus holds potential for scaling CASI technologies.

Zone 3

is dominated by rice-rice systems. It is characterized by low laying landscape in the catchment of the Brahmaputra and Meghna rivers in Bangladesh and Assam with high climatic shocks, low mechanization due to poor connectivity and infrastructure, and less scope for cropping intensification due to low lying land with excess moisture. However, it has a good coverage of short duration oilseed crops. 80% of farming households are categorized as small and marginal, and suffer from poor market access. This zone consists of 35 districts from Bangladesh, Assam and West Bengal, with a total cultivable area of 4.8 million ha. There is potential to promote integrated fish and rice farming systems, improved/hybrid high yielding varieties and deep water tolerant rice varieties, and suitable short duration oilseed and pulses to significantly improve food security and livelihoods for farmers in this zone.

Zone 4

is dominated by rice-rice cropping systems, present on 64% of net sown area, with rice-wheat under 11% of land. This zone has the highest cropping intensity in the EGP at 237%, and the highest yields of rice, wheat and maize. This zone is fairly well mechanized with developed markets and 69% of the cultivable area is under irrigation, although arsenic contamination of groundwater is problematic. This zone consists of 15 districts in Bangladesh (12) and West Bengal (3), and has 2.29 million ha of cultivable land. There is high potential to promote CASI technologies for improved productivity of wheat and maize.

Zone 5

cropping systems are dominated by kharif rice and low input pulses and oilseeds. The zone is characterised by low cropping intensity (143%), low availability of irrigation (10%), low crop yields, a lack of mechanization and poor market networks, and is highly vulnerable to climatic shocks. It has a total area of 2.23 million ha cultivable land. Of the total, this zone consists 17 districts (12 districts from Assam and 5 from Bangladesh), and covers coastal areas of Bangladesh and the foot hills of Assam. However, it has a relative abundance of small and medium farm households, and has good potential to utilise surface water irrigation and CASI technologies to improve productivity and household food security.

Zone 6

is dominated by rice-wheat cropping systems (41% of net sown area), with rice-maize an emerging system that is gaining popularity. The zone is characterized by poor farming households, high rates of share cropping, complex social structures and poor coordination among existing institutions and government schemes. There is access to irrigation on 56% of cropped area, but it is uncertain and costly. Soil acidity is a problem that further constrains yields and options for diversification. Wheat productivity is low due to late sowing, poor mechanization and land fragmentation. This zone consists of 30 districts (28 of Bihar and 2 of Eastern UP) and has a total cultivable area of 5.5 million ha. This zone is well mechanized for tillage which is very resource intensive, and so there is potential to promote other mechanized CASI practices.

4 Farm scale improvements to food, energy and water security

4.1 Productive and sustainable technologies

More than 3,000 participatory field trials were conducted in 40 nodes (each node consisting of one or more villages) in eight districts across three countries. These field results, in conjunction with simulation using the APSIM model, have been used to examine trade-offs, resilience and stability of technology performance in different locations and under future climate scenarios.

The technologies tested were based on CASI principles, which include a mix of minimizing soil disturbance, maintaining continuous soil cover, and crop diversification and rotation. The portfolio of technologies tested includes improved varieties of rice and wheat, crop diversification (maize, lentils, oilseeds, leafy vegetables), crop management strategies (zero and strip till (ZT, ST), relay and intercropping, stubble/residue retention, improved water management) and small-scale mechanization (e.g. planting techniques). The combination of these practices applied within effective institutional settings is intended to increase the efficiency of the FEW nexus at the farm scale. Simultaneous outcomes were observed including improved profitability and productivity, household nutrition and food security; and reductions in labour, water and energy inputs in crop production systems. Results from field trials were considered both on an individual crop basis and from a systems perspective (i.e. rice-maize, rice-wheat, rice-lentil and rice-rice).

CASI practices generally resulted in comparable or slightly higher yields than those under conventional tillage (CT), with an average 6% increase in yield (t/ha) across all systems. This ranged from -4 – 12% for rice; -1 – 13% for maize; -3 – 14% for wheat and 1 – 24% for lentil. However, the real gains were not in yield per se, but in the productivity increases that come with using less labour, water and energy, and therefore less cash inputs, to achieve these yields. Wheat and maize yields were highest under zero/strip till; for lentils, zero till or relayed management performed best.

The use of CASI technologies resulted in labour savings, as well as reduced drudgery, often for women. Average labour savings as a result of using CASI technologies compared to CT were 37% in rice-maize systems, 26% in rice-wheat systems, 34% in rice-lentil systems and 41% in rice-rice systems. CASI techniques include mechanization which reduces labour requirements by eliminating or reducing the number of tillage operations, allows crops to be established quickly, and reduces the amount of time taken for irrigation. Much of this time saving is for women, who can pursue other work either on or off-farm. This element of CASI makes it attractive to farmers in locations where labour scarcity is a barrier to improved household productivity.

The application of CASI technologies also results in improved gross margins; economic analysis indicates that the introduction of zero tillage maize, wheat and lentil with direct seeded or unpuddled transplanted rice can increase net returns by an average of 19% in rice-maize systems, 31% in rice-wheat systems, 17% in rice-lentil systems and 94% in rice-rice systems. Net returns (AUD/ha) in rice-maize systems ranged from $630 - $1,025 for rice, $1,021 - $2,486 for maize and $1,660 – $3,385 for the system. In rice-wheat systems this ranged from $261 - $1,099 for rice, $453 - $1,026 for wheat and $1,025 – $1,964 for the system. In rice-lentil systems, this ranged from $170 - $1,118 for rice, $1,016 – $2,028 for lentil and $1,677 – $2,859 for the system.

Increases to gross margins using CASI compared to conventional practices were experienced by both male and female headed households. Importantly, the increase in returns for female headed households was usually greater than for male headed households, demonstrating higher impact and improved benefits for women. Figure 32 shows examples of the increases to gross margins ($/ha) and includes a range of districts and cropping systems (rice-maize, rice-wheat, rice-wheat-maize).

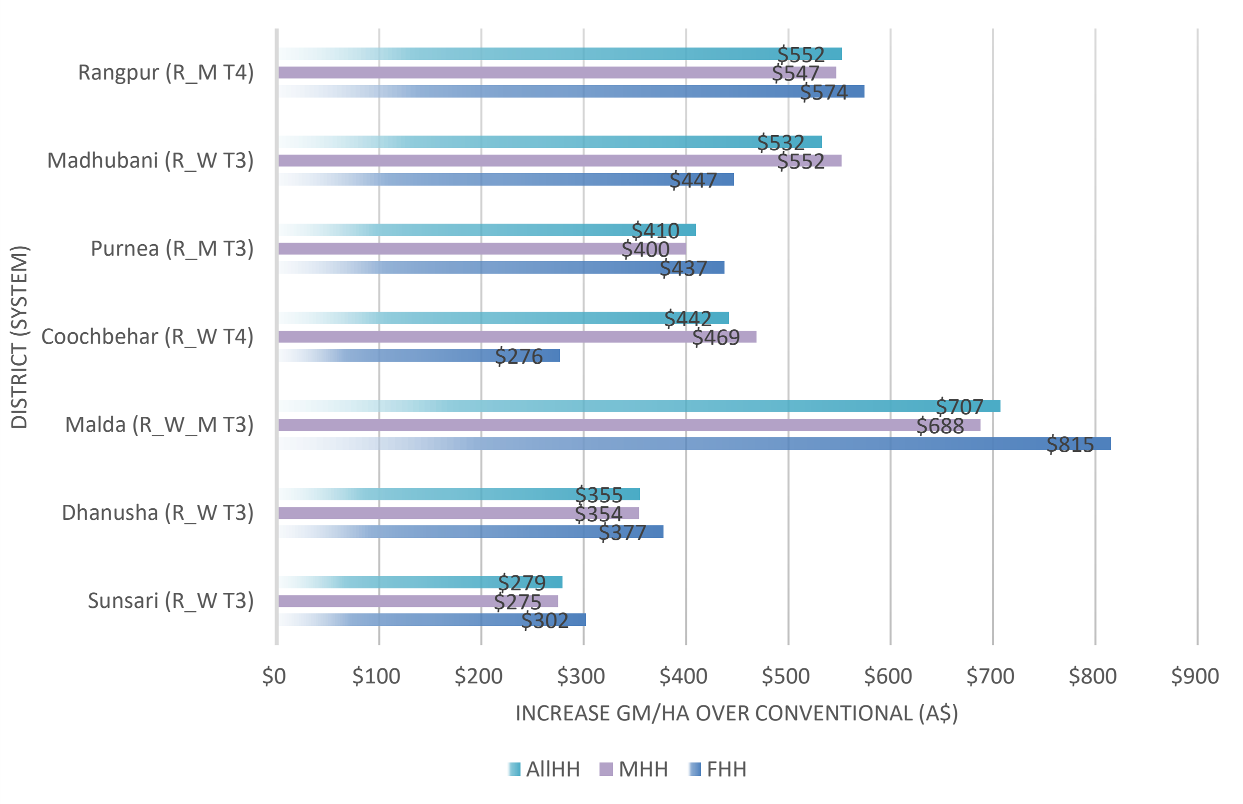

Figure 3 Impacts on men and women-headed households; increase in gross margin ($/ha) compared to conventional tillage (Rola-Rubzen & Murray-Prior, 2018).

Considering benefits at the farming system level is important from an intensification angle, since it makes more productive use of available resources and accounts for interactions within cropping systems, such as use of residual moisture and fertilizer, and the effects of improved soil structure. Where leafy vegetables (green pea, napashak, spinach, red amaranth, coriander, fenugreek, bathuashak, potato) were intercropped with maize, household food security was improved and profits increased by between $3,615/ha - $8,564/ha. Farmers also reported additional benefits in suppressing weeds, and contributing to household food nutrition, particularly for women and children.

Mungbean and jute are additional crops to aid intensification of rice-wheat systems in particular. Mungbean is not suitable for flood prone areas, but in other parts of the EGP can be successfully used to increase productivity and profitability when integrated into a CASI based system. Profitability was demonstrated to increase by 62-78% for rice-wheat-mungbean and 18-35% for rice-wheat-jute, with attendant reductions in energy and labour use. Increasing cropping intensity increases gross margins, as would be expected, although this is not always the case in conventional production systems. Given the range of locations the project worked in, existing information can be tailored to individual sites for recommendations for different locations, institutional settings and agro-ecological zones.

4.1.1 Water and energy productivity

In addition to improved or maintained yields, lower labour requirements and higher gross margins, improved water and energy productivity is also one of the major benefits from using CASI techniques compared to conventional crop production practices. The application of CASI approaches demonstrates a positive example of the food-energy-water nexus at the field and farm scale, with benefits for all elements when strategic and relevant farming system techniques are employed. Results from SRFSI show that it is possible to reduce water application at the field level by up to 30% by using lower water demand crops and strategic use of residual soil moisture. At the same time, energy inputs have been reduced by 5-20% through the use of minimum tillage, reduced pumping for irrigation and improved fertilizer use efficiency.

For kharif (monsoon) rice crops, farmers often use available rainfall and use supplemental irrigation sparingly, if at all. Thus, changes to water use for kharif rice vary with the implementation of CASI; where no supplementary irrigation was used previously, water use often increased with the addition of irrigation; and where irrigation water use was used previously, it often decreased when more efficient CASI practices were implemented. Rabi (dry season) crops apart from lentil require irrigation in all locations, and CASI results in less water applied at the field scale. Figures given here refer to average changes across all locations in the study area; the range is given in brackets. In rice-maize systems, water application at the field level was reduced by 5% (-22% to +38%) for rice, 14% (-27 to -7%) for maize, and 12% (-27% to +7%) for the rice-maize system as a whole. For rice-wheat systems, water application at the field level was virtually unchanged for rice at -1% (-34% to +20%), reduced by 17% (-28% to 0%)% for wheat and 16% (-36% to +1%) for the rice-wheat system as a whole. In rice-lentil systems, many farmers grow lentil without irrigation even in the dry season, perceiving soil moisture as adequate to attain reasonable yields. In these systems, field scale water application increased by 12% (-9% to +139%) for rice, decreased by 8% (-11% to -28%)% for lentils and increased marginally by 4% (-28% to +139%) for the rice-lentil system as a whole.

CASI practices increase water productivity in several ways. Mechanised rice establishment methods let farmers achieve a rice yield comparable to that under transplanted rice while using less irrigation water. Mechanised rice establishment, in conjunction with improved seed varieties, can also reduce the growing season length: this, linked with mechanised and timely sowing of rabi crops into standing rice stubble, enables winter crops to access residual soil moisture and thus establish and finish sooner. These rabi crops require less irrigation water across the season than under conventional tillage, and have reduced exposure to heat stress late in the season. Retained residues also increase organic matter content of soil, thereby increasing soil water holding capacity, reducing soil evaporation losses and insulating crops against heat stress. Additionally, the rabi crops promoted under SRFSI (e.g. wheat, maize, legumes) all have lower water demands than traditional boro (rabi season) rice or jute. Finally, laser land levelling of soils reduces the amount of water required in each irrigation event in both rabi and kharif crops: over a cropping season savings of up to 30% of irrigation water applied in conventional tillage can be achieved.

Using CASI techniques also reduces energy inputs for crop production. In rice-maize systems, energy inputs are reduced by 0-19% for the rice crop, and by 0-13% for maize and the rice-maize system as a whole. In rice-wheat systems, energy inputs are reduced by 10-20% for rice, and by 5-20% for wheat and the rice-wheat system as a whole. In rice-lentil systems, energy inputs are reduced by 5-17% for rice, 25% for lentil and 15% for the system as a whole. Reductions in the energy expended to produce a crop under CASI practices come primarily from savings in diesel from minimised (or no) tillage. For example, in the West Bengal districts of the SRFSI project, the fuel required to establish a rice-wheat-mungbean or rice-maize system using CASI approaches is 78% less than under CT.

Additional savings in electricity result from reduced pumping of irrigation water, since lower irrigation water application using CASI production methods requires less time and therefore fuel/electricity to irrigate, decreasing energy use and irrigation costs.

An additional benefit from reduced water and energy use is a convergent reduction in greenhouse gas emissions. GHG were estimated based on total energy requirements, and then converted to GHG equivalents. In rice-maize systems, reductions in carbon emissions were up to 17%. This was around 10% on average (up to 30%) for rice-lentil systems and 15% from rice-wheat systems.

4.2 APSIM

On-farm trials have provided proof of the impacts of CASI adoption on various elements of the farming system. These field trials can be used as a basis from which to explore changes in the longer term using simulation modeling. The APSIM model is a crop simulation models that can be used in conjunction with field level results to generate information on the long-term variability and risk in the system under different management options. APSIM's value is in extending the learnings beyond the relatively short time period of the project, to provide information about what happens in the longer term (i.e. 20+ years). APSIM can simulate soil moisture dynamics, total water use and soil organic carbon. It has also been tested in East Asia and simulates increased CO_2 concentrations well.

The model has been validated for 30 nodes across the study sites, and is being used to simulate the biophysical performance of the system daily in terms of crop yields, water use, soil dynamics, fate of nutrients and residues, energy use and GHG emissions. Output data can be used to calculate gross margins, water use efficiency, energy use efficiency etc. It will be used to investigate various management scenarios and the effects of current and future climate change on yield, profits, water use, soil dynamics and GHG emissions. The modelling efforts are underway and, depending on the local modelling capability, are at different stages of applications across the project districts. These results provide an additional benefit to field trials and estimate the resilience of current and improved cropping patterns to climate variability to inform FEW integration and trade-offs under different climate and policy scenarios.

5 Effective institutional arrangements to support sustainable farming systems

5.1 Institutional arrangements

Understanding agricultural innovation systems means recognizing the need for institutional arrangements that work well within an effective enabling environment if CASI is to be adopted on a wider scale. The project has worked to improve the enabling environment through initiating and supporting multi-stakeholder groups called Innovation Platforms, interaction with existing agencies, and capacity building of key local and regional stakeholders.

Farmers in the EGP rely almost entirely on the small scale private sector to access agricultural inputs, and sell their outputs through local markets. Public extension systems generally do not reach the majority of farmers, particularly women-headed households or those of other minority groups, and so access to information via alternative means is required. In Bihar and West Bengal, India, less than 10% of farmers access extension services from either public or private institutions. Sustainable adoption of CASI techniques requires access to information about CASI, specific machinery, quality inputs and markets at the right times. Some form of aggregation is required to increase farmers' bargaining power and reduce transaction costs for businesses to engage with them.

Institutional arrangements to promote the adoption of CASI in the SRFSI project were predicated on the idea of working with multi-stakeholder groups or Innovation Platforms (IP). IP are groups of stakeholders that interact within an agricultural system to solve problems at the local level. The project has supported the operation of 34 IP across the three countries, which coordinate local stakeholders to address issues in input supply, access to machinery, marketing and cross-site learning. Importantly, the experiences in working with IP across three countries has given the team valuable experience in applying these approaches in the South Asian context, and will make a valuable contribution to the literature, which is often Africa-centric.

Some of the problems addressed by IPs include limited availability of quality fertilizers, herbicides and seeds at the right time; limited availability of CASI machinery and lack of skills for repair and maintenance; and limited technical knowledge. These groups have actively included the local private sector, who benefit from increased business opportunities, for example through providing custom hiring services of small scale machinery (such as bed planters, zero/strip till drills, Happy Seeders, laser levelers and mechanical rice transplanters, reapers); agro-processing; and seed multiplication and certification services.

The project has demonstrated the effectiveness of the IP approach to link private, civil and public-sector stakeholders. Together, these groups have built capacity and networks that can self-organise and problem solve to provide information, improve commercial viability, ensure machinery access and identify and exploit market opportunities. IPs are also a way to leverage public extension systems through coordinating local stakeholders and providing an interface between extension officers and smallholders. Local IPs can be linked to higher levels of decision making and resourcing. Importantly, this approach has been flexible and able to be applied differently in the different locations – and a key strength is its ability to be adapted to different contexts and with different stakeholders as the driving force.

5.2 The private sector

Access to improved markets and services for smallholder producers and small enterprises is key to the successful adoption of CASI approaches. In the EGP, the large-scale private sector is noticeably absent, and most farmers rely on the small scale private sector to purchase inputs and sell surplus to market. The prevalence of these types of businesses has been recognized and engagement with the private sector has been instrumental in achieving the current levels of adoption, including with local service providers for CASI mechanisation, as well as with larger entities such as JEEViKA and Green Agrevolution in Bihar, and Satmile in Coochbehar, West Bengal.

Dealerships have been formed with local traders and service providers and they have been provided training and support in technical as well as business management aspects of their work. A range of machinery manufacturers have been engaged, including dealers and service providers, to refine equipment suitable for CASI approaches. For example, bed planters, Zero/Strip till (ZT/ST) drills, Happy seeders, laser levelers, mechanical rice transplanters and power tiller operated seeders have been exchanged across borders and adapted for local conditions. These links are seen to create opportunities for further outscaling and removing barriers to adoption. Inventories of local agro-dealers have been compiled in each district to facilitate investment by larger companies. A major farm equipment manufacturer in India has opened a branch in West Bengal, and other large corporate entities have plans to support field activities. As well as with existing partners, SRFSI has started exploring the possibility of attracting regional level private sector partners that have similar goals and objectives, to encourage investment to support SRFSI promoted technologies. This includes linking smallholder producers to higher value chain markets through improved product development, organizational capacities and new partnerships with private sector investors.

The project has supported micro-entrepreneurship through capacity building in a range of different approaches. For example, in West Bengal, India, the project has worked with Farmers' Clubs (FC) and Farmer Producer Organisations (FPO), which have been promoted by the National Bank for Agricultural Development (NABARD). The FC and FPO supported by the project vary in their length of operation, geographic spread and subject focus. In many ways, these organisations are structured with many of the features of cooperatives, which require certain critical factors for success. These include having a comparative advantage over investor owned firms, which exists for many of the existing groups at present; and having high levels of social capital among members, which often depends on the size and structure of the group's membership. Successful models require considerable investment from external parties in terms of financial support, training in leadership and management capacity. Additionally, the project has partnered with Business for Development (B4D), an Australian NGO, to design and test business models that will encourage the private sector in outscaling CASI technologies in the region. B4D are working with Green Agrevolution to manage the implementation of an agribusiness model that uses Farmer Service Companies and micro-entrepreneur centres in Purnea using the locally accepted DeHaat model.

The current business models and institutional arrangements described above have been specifically analysed from a scaling and private sector integration aspect and for their ability to work in a commercially sustainable way. The specific business activities include Custom Hiring Centres (CHC) for CASI related farm machinery, input related services (seed, fertilizer procurement, crop advisory) and marketing services. For accessing farm machinery, including

CASI specific machinery, farmers have the options of either buying outright or renting machinery and/or services from a CHC. Buying is a high capital cost proposition hence rental models are gaining popularity. Outside the project areas, these models are not always providing CASI machinery yet, but where CHC are already in place there is an option to include these machines.

Business models for farmer groups cannot be viable based on custom hiring services for CASI machinery alone. This is primarily because the capital cost of machinery is usually high, and the rental income obtained is only for a limited time period in a season (20-30 days). This has been observed for all the regions studied (Purnea in Bihar, Coochbehar in West Bengal and Rangpur in Bangladesh). Custom hiring centres must include CASI within a portfolio of services. Four wheeled tractors offer the prospects of revenue through other farm and non-farm operations whereas self-propelled CASI machinery in the existing context is capital intensive and has no economic usage outside the farm.

In India, sustainable business models include diversified revenue activities related to input supply, custom hiring and marketing. As observed from the DeHaat model, marketing services offer the highest commission levels to business and farmer groups. Satmile and linked Farmer Producer Organisations currently provide input services (and now with this project CASI machinery dealership and hiring). They should also look at providing marketing services as also popularise CASI technology in the area.

In Bangladesh, there is an absence of structured small and medium level business formats like DeHaat or state support incubated farmer groups like Satmile. The financial capacity of Innovation Platforms is marginal. NGOs like RDRS who are doing the crucial work of linking the private sector across the agri-value chain with smallholders should consider setting up sustainable business activities on the lines of DeHaat and/or Satmile, including marketing, banking and mechanisation services. Future machinery demand in Bangladesh appears to be moving towards scale economy related four wheeled tractor, and other larger farm machinery could form a larger chunk of future demand unlike the smaller machinery that has successfully dominated the farm machinery landscape in Bangladesh until now.

Farmers in all areas need to be brought closer to formal banking services. In India, farmer groups should have linkages with several digitisation efforts in banking services. There would be opportunities where private sector companies in India (mobile and payment services companies) will find farmer groups as business partners in the region. In Bangladesh, the level of digitisation is less but still NGOs like RDRS can look at such services as a strategic future business. In India, the corporate social responsibility (CSR) programs for value chain linked companies should be linked up with farmer groups enabling scaling of CASI business and bringing markets closer to farmers.

Policy interventions that provide 'smart subsidies' based on usage rather than ownership (for CASI machinery), need to be looked at for the future. Specific smart subsidy administration via farmer groups also needs to be planned. The usage of ICT in service provision of usage-based subsidies needs to be piloted now.

Business models to improve access to farm mechanisation and services should contain custom hiring as part of a farmer service model that includes input, advisory and marketing services. Such business models within a wider enabling environment with effective institutional support and aligned policies can improve agricultural productivity, profitability and sustainability in the region by making CASI available to a large cohort of farmers across the EGP.

Satmile Satish Club, West Bengal

The Satmile Satish Club "O" Pathagar in Cooch Behar District, West Bengal started in 1960 and has been through several reorganisations and changes of focus. Most recently, it has been registered as a Farmers' Club (FC) and is an integral part of the FC program in Cooch Behar district. It works like a nodal Farmers Producers' Organisation (FPO – which are registered under the Companies Act). Satmile is supported both technically and financially by a number of organisations including universities (UBKV) and government programs and departments (KVK, DoAWB). It also has links with the National Agricultural Bank (NABARD), credit agencies and machinery dealers. Other regional FCs are linked to Satmile for facilitation of government assistance programs, as well as being business customers for commercial activities undertaken by Satmile such as farm machinery dealership and custom hiring of farm machinery.

Members benefit from cheaper purchases of inputs, such as fertiliser and pesticides, and are able to access loans more easily. The Club plays the role of a 'single window service providing unit' in the district and its adjoining areas. The service providing includes both farming (agriculture, animal husbandry, fishery, processing) and non-farming (health, education, child care). The Satmile Club supports women's involvement in improving production. As well as being involved with on-farm trials to understand new technical developments like ZT machinery, women's groups are undertaking value added work such as mushroom cultivation that and processing of dal lentils for sale in local markets. Satmile has benefited from working with the SRFSI project in terms of building skills in gender inclusion.

As a part of the SRFSI project, CASI technologies including Zero Tillage (ZT), mechanical transplanters and diversified cropping options have been promoted and are becoming popular with the farmers of the area. This has led to the need for Custom Hiring Centres (CHCs) for machinery, which has been added to the Satmile portfolio. Research and demonstration sites have shown a reduction in production costs of the crops by as much as 10-15% thereby increasing the potential demand for CHCs.

Green Agrevolution, Bihar

Green Agrevolution is a social enterprise company that started in 2012. One of its major business activities is promoting the DeHaat model, which is an independent business model providing end-to-end services to farmers. The DeHaat model provides full services for farmers, including input, crop advisory and marketing activities through a two-tier model:

1. Nodal level Offices that look after a district, manage input supply and crop storage.
2. Micro Entrepreneurs (also called Channel Partners) at village/sub-district level, where the Microentrepreneur is a business partner of DeHaat. Microentrepreneurs register farmers, supply inputs and services (crop advisory, machinery hire), and serve as an aggregation point for collection of market for sale.

In addition to nodal and local level business partners, the DeHaat model operates an ICT based platform which registers all farmers, maintains records of farmer profiles, provides a detailed list of and access to inputs (seed varieties, fertilisers, crop protection, machinery for hire), acts as a site for market linkage (buyers can subscribe and see produce available), records farmer feedback, and provides customised crop reminder calls based on profile and inputs purchased. Additionally, DeHaat has a helpline for farmers to access information at any time, with customised recommendations available based on their profile. There are currently 62 DeHaat Centres that reach over 26,000 farmers. Business for Development (B4D), an Australian NGO, were commissioned to work with Green Agrevolution to manage the implementation of an agribusiness model that involves the establishment and evaluation of a Farmer Service Company (FSC) and 5 micro-entrepreneur centres in Purnea (Bihar, India). This FSC uses the DeHaat approach and software application, with strengthened links to input companies, machinery suppliers, farmer credit facilities and market partners.

For DeHaat, approximately 70% of business is Marketing related and 30% is Input Services related. DeHaat sees a value in CASI related farm machinery services provision for strengthening their relationship with farmers. DeHaat has made strong links with farmers on the basis of their crop advisory services for fertilizers and pesticides, a stage where farmers often lack good advice. CHC for ZT can be seen as a value added advisory service, for advice related to ZT/CASI technology. Therefore, CASI machinery services and knowledge provision are a value-added service for DeHaat.

In Purnea, another partner of SRFSI is Jeevika, a national NGO who have established a women only maize marketing company called Aranyak. Farmer producer groups pay a small fee to buy shares in the company; only female farmers are eligible to join, and must have a bank account so that funds can be transferred directly. Aranyak buys maize at market prices and pays within 3-4 days. The company trades on the NCDEX Futures Market, and once maize is sold profits are shared 70:30 between Aranyak shareholders and the company. At the moment they have 2,600 shareholders and have registered 10,000 altogether who sold maize in the 2017-18 rabi season. DeHaat recognises the value of linking with Jeevika in areas where there is overlap between the current activities. This may benefit DeHaat not only in registering farmers, but also in forward thinking models for gender inclusion.

6 Benefits beyond the farm gate

6.1 Gender

The overall goal of SDIP has a specific focus on benefits for women and girls, and the participation of women at all levels in the SRFSI project has been critical to its successful implementation. In the project area, it is generally understood that agriculture is becoming increasingly feminized in the EGP due to the out-migration of men who seek off-farm employment. This has resulted in an increase in the number of female-headed households, who are often disadvantaged because they have less access to critical resources including information, credit and services. However, the complex socio-cultural makeup of the region makes studying the role and status of women in agriculture in more detail warranted, as there are also reports of women exiting agriculture in large numbers in some places.

On average, 50% of all participants in project events were women, and this has increased from 33% for the period 2015-16 to 62% for the second half of 2017. This is the result of particular attention that has been paid to creating space for women to participate, including though women only field days and women only and joint Focus Group Discussions. The most common activities that women participated in were scaling out activities (90% of participants were women in 2016-17) and field trials (54% of participants were women). Focus Group Discussions (36%), farmer field days (35%) and exposure visits (27%) had a relatively good attendance by women, although the trend declined with the life of the project. FGD included men and women only groups, as well as combined groups. Training and workshops were least well attended by women (25%), although participation did increase throughout the project from 21% initially to 33% most recently. In many cases the activities which required travel outside the village were less well attended due to cultural and social reasons women are often unable to leave their household and travel. It is very encouraging to note that outscaling activities have very high levels of participation, which indicates that scaling CASI is well placed to have significant benefits for women across the EGP.

Since 2016, the project has focused beyond participation rates, to evaluate the benefits to women. According to women, the key impacts of CASI are higher incomes; a reduction in farm labour use; lower labour and production costs; reduced drudgery; more time to do other productive tasks and for leisure; better education for children; and better family nutrition. A household survey being conducted in early 2018 will further quantify the impacts for women who have adopted CASI. Analysis of the data from more than 3,000 field trials has shown that gross margins for male and female headed households who have adopted CASI are similar, and often even better for female-headed households. Further, as women often have lower returns under conventional practices, the relative increase in gross margin (i.e. net financial gain) is higher for female-headed households.

At an operational level, the project has been instrumental in increasing awareness and mainstreaming of gender inclusion among the SRFSI project and partner teams. There has been an increase in gender awareness and a profound appreciation of the importance of incorporating gender aspects in all components of the project, as evidenced in discussions and the adoption of the gender protocols within the project. The use of gender protocols and data gathering tool are now a standard practice in all project activities to monitor participation of both men and women in various project activities. The effect of this has been to increase the awareness on the importance of including women in the planning and implementation of project activities, thus improving their inclusion rates and ensuring better impacts for women and children.

6.2 Boosting resilience to climate change through adaptation and mitigation

Resilience to climate change can be boosted by both increasing ability to adapt to changes in climate (adaptation), and by mitigating future climate change (mitigation). CASI approaches contribute to climate change adaptation through improved agricultural practices that increase resilience by improving resource-use efficiency; and decrease vulnerability through exposure, sensitivity and adaptive management. Climate change mitigation is enhanced by CASI approaches that decrease emissions and increase carbon storage in soils. CASI based approaches are now being implemented by 75,000 farmers on more than 15,000 ha of agricultural land. These figures (number of beneficiaries and areas under CASI) will significantly increase in 2018/19, although tracking numbers is a challenge.

CASI approaches include crop management techniques that allow adaptation to climate variability such as changes in rainfall timing and quantity, increased temperature, and associated emergent pest and disease problems. Cropping patterns that include diversified and integrated cropping systems reduce risks associated with monocropping; for example, introduction of crops such as maize, wheat, mungbean, lentil; and maize intercropped with potato, peas and leafy vegetables such as spinach and red amaranth. Water management can be improved by using reduced or no tillage crop establishment using mechanised methods, incorporating varieties with different growth periods, maintaining residues for soil cover and including annual legumes in the crop rotation. A combination of these approaches leads to reduced water use by maintaining soil water content through reduced evaporation, better irrigation management methods and crops with lower water use requirements. Water productivity is increased by up to 30% when using CASI approaches. Additionally, any work that reduces costs for irrigation in terms of groundwater pumping can increase resilience to climate change because it makes irrigation available to more farmers.

Soil analysis after three years of long-term on-farm trials showed that Soil Organic Carbon (SOC) was always higher in ZT plots than CT plots, indicating build-up of SOC in CASI plots compared to conventional tillage. This increase in soil carbon improves adaptation to climate variability by improving water and nutrient holding ability of soil, and storing carbon (mitigation). APSIM modeling gives the ability to model long-term changes to soil carbon.

Innovation Platforms are institutional innovations that can help farmers manage climate change through developing strategies with multiple stakeholders, and creating space for better exchange of information between local communities and decision makers. The project has demonstrated that this form of institutional arrangement can benefit farmers and the local private sector, and is adaptable to different locations, policy settings and levels of stakeholder engagement.

In addition to helping farmers adapt to climate change, CASI practices can also help farmers mitigate greenhouse gas emissions. Conservation agriculture contributes to climate mitigation by reducing inputs and tillage and maintaining soil carbon levels, while maintaining or increasing productivity. CASI approaches result in a reduction in greenhouse gas emissions of between 10-30% in rice-maize, rice-wheat and rice-lentil systems. Fuel savings of between 25-50% are reported for CASI approaches, relative to conventional production approaches. CASI approaches also contribute to a reduction of nitrogen inputs into the system by promoting legumes as part of a diversified cropping system, and improving soil nutrient holding ability due to increased levels of SOC. A focus on crop diversification means that rice production in the Rabi season is replaced by alternative crops with lower water requirements, and eliminates ponded irrigation of rice, reducing methane emissions.

6.3 Sustainability

Sustainability can be defined in many different ways, including financial, social, environmental and institutional. The results from Phase 1 results demonstrate sustainability in all these areas. Aligning these elements should have positive effects on the ability of project practices and approaches to continue to be implemented and adopted outside of project activities, and there is evidence to suggest that this is already occurring.

Financially, the implementation of CASI approaches as part of a wider enabling environment has shown improved returns for farmers, including female headed households, and for local businesses. Improved returns from diversified systems. The project has explored different business models that will encourage the private sector in out-scaling CASI technologies in the region. For example, the company Green Agrevolution have established a Farmer Service Company and 5 micro-entrepreneur centres in Purnea district (Bihar) using the local DeHaat model of operation.

Through the IP initiated as part of the project, sustainability is enhanced by strengthening connections between local stakeholders, and helping to remove barriers to implementation of CASI technologies. For example, one IP in Bihar identified problems with middlemen accurately weighing produce and assessing quality in maize marketing. The local NGO JEEViKA now offer services to purchase maize, weigh using electronic scales, and grade based on moisture content and quality. Farmers have been trained to test their produce before it is sent to warehouse facilities, allowing them to take control of their business practices and improve income generation. IP have also facilitated linkages between manufacturers and dealers in some locations, to attract rural youth to come forward as local service providers and entrepreneurs. The concept of custom hiring is gaining popularity in all nodes; the total area under CASI using this approach was 2,342 ha in 2016-17.

Socially, the productive and resilient farming systems tested here have been proven to benefit a range of community stakeholders, as well as local government agents. The project sees capacity building as a key element in the sustainability of project outputs. A total of 9,264 farmers (30% female) were trained in CASI technologies, value chain and market development, entrepreneurial skills development, and seed systems management; 4,688 farmers (28% female) participated in exchange visits; 7,555 farmers (43% female) participated in Focus Group Discussions); 13,456 farmers (35% female) attended field days; 787 farmers (10% female) received service provider training; and 4,469 farmers (32% female) attended Innovation Platform training. More than 530 scientists/technicians and 1,282 project personnel have also participated in training events and study tours through the project. This capacity helps to reduce knowledge gaps, develops community capacity to take ownership of activities and outputs, and leads to the internalisation of project approaches, with tangible outcomes.

Partners have started internalising SRFSI promoted CASI technologies by including them into their regular programs (e.g. West Bengal, Nepal). For example, the Department of Agriculture in West Bengal have commissioned a million dollar project with UBKV under the Rastriya Krishi Vikash Yojna (RKVY) scheme, which promotes agricultural development in an integrated manner, and commits central funds to state programs. Similarly, an effort is also being made to integrate CASI into the Prime Minister's Agricultural Modernisation Program in Nepal.

Finally, environmental sustainability is improved by wide scale adoption of CASI approaches at the farm level, because it results in reductions in water and energy inputs and carbon emissions. CASI yields are demonstrated to be more stable in extreme (poor) years, which are projected to increase. CASI also increases the efficiency with which nutrients are used in the system.

7 Policy settings

Sustainable Intensification requires policies and institutions that help smallholders minimize transaction costs and potential risks involved in adopting new technologies and practices and accessing markets. IFPRI (2017) analysed existing policies in the food, energy and water sectors of Bangladesh, Nepal and India to understand how they affect (i.e. incentivize or inhibit) widespread adoption of technologies and practices for sustainable intensification. Six major constraints to sustainable intensification were identified, and which are also evident from the results described within this report. These constraints include:

1. Small and fragmented landholdings
2. High cost of irrigation despite a relative abundance of groundwater
3. Reliance on rental markets for machinery in a location where rental markets are underdeveloped or uncompetitive
4. Poor access to markets
5. Low and volatile returns from agriculture
6. Weak institutional settings for extension, credit and insurance.

The policies that can go some way to addressing these constraints and affect the adoption of sustainable intensification, include decisions made about food, energy, water and agriculture, particularly in relation to mechanization. It is important to note that in India, agriculture is part of state-based policy decisions, although the national government does influence the policies and programs by providing finance for their implementation. In Nepal and Bangladesh, agricultural policy is determined at the national level. However, the implementation of policies differs by country and is a concern across the region.

Food policy in the EGP is focused on ensuring that the key staples of rice and wheat are available at affordable prices at all times, and achieving and sustaining self-sufficiency in these staples is the cornerstone of food policy, research and extension efforts. However, this focus on staples does not cater for improvements across the entire food system, and does little to contribute to high level calls for improvements to household incomes, such as in India where there is a target to double farmer's incomes. This shift in focus needs to include a parallel improvement in understanding and skills to address the new challenges for sustainable food systems, from research to extension. All three countries use heavy input subsidies, price controls, import and export restrictions and other market distortion tools to assure self-sufficiency. The Government of India also operates a minimum support price (MSP) scheme for rice, wheat and pulses, and maintains a large buffer stock of these staples. While these policies may achieve the desired results in terms of self-sufficiency, they also discourage sustainable intensification and diversification into high value crops. To appeal to policy makers, CASI needs to demonstrate that it is able to maintain or improve cereal yields in addition to other benefits, as government will not want to reduce consumer access to staple foods.

Energy policy for irrigation heavily influences the size and structure of the groundwater irrigation economy, and this is evident across the EGP. Costs for irrigation using diesel as an energy source are generally higher than those using electricity, and this is particularly true for the 75% of farmers who access irrigation through water markets. Water markets in the EGP are uncompetitive and increases in pump density have not reduced costs and are not likely to, until alternative cheaper energy sources are found. Improving power supply to rural areas is one way to make irrigation more affordable, but this is not a short-term solution. Solar power may be a suitable option to reduce costs, and is being promoted by governments in India at the state (e.g. Bihar) and national level, albeit with ineffective high capital subsidies. Other states and countries can learn from ineffective policies currently being implemented for example in Bihar, in order to devise more appropriate policies that incentivize technological and business process innovations instead of relying solely on high capital subsidies. Care must also be taken to ensure that promoting solar power does not result in unchecked use of groundwater.

Mechanisation of agriculture is a policy priority in all three countries. In India, provision of capital subsidies is a major component in all government schemes, usually in the range of 25 – 50% of capital cost. This should be targeted towards machinery that promotes resource conservation, and ineffective machines removed from subsidy lists, e.g. rotavator. However, the government continues to subsidize all types of machines at the same rate, thereby, sending confusing signals to farmers. There are several policies which allocate part of the mechanization subsidy budget for women and some also offer additional financial assistance. The results of these policies are not well understood in terms of benefits to women. Nepal's agricultural mechanization policy also relies heavily on capital subsidies, and imports are subject to duties and local taxes. The combination of high subsidies and low budgets for those subsidies means that a very small number of people can get the subsidy, and it impedes the open market.

Bangladesh has a very different approach to mechanization policy compared to India and Nepal. The agricultural equipment sector is deregulated and there are no or very low import duties and other domestic taxes on agricultural equipment and spare parts. Subsidies are available for a range of farm equipment, although bank loans are limited. Agriculture is mechanized to a much higher degree in Bangladesh (i.e. 80% of land preparation compared to 45% in India) due to the emergence of competitive machine rental markets even in the context of very small landholdings and low capital endowments of most farmers.

There is a real opportunity to share learnings between the countries. For example, benefits in Bangladesh in the deregulation of machine imports and taxes, and better analysis of the benefits for targeting women farmers in India. Policies to ensure farmers have access to CA equipment should go beyond capital subsidies to include extension efforts and effective institutional arrangements to promote benefits to farmers and micro-entrepreneurs alike. Options include subsidies based on use rather than purchase, and promotion of custom hiring centres are needed.

Effective extension arrangements are critical to introduce farmers to new technologies such as CA based techniques, as well as support when farmers are adopting. All three countries have taken steps to reinvigorate their public extension systems in the past decade. There are similarities in the relatively new extension policies that emphasise the need for demand-driven, decentralized and interactive extension services; multi-pronged extension using different service providers and ways of communication; development and use of farmer groups; including advice related to weather, price and public-sector schemes as well as agronomy; and the use of modern ICT to exchange information with farmers. However, despite these commendable intentions, public extension systems continue to have low coverage and impact on adoption in the EGP, and use of modern technologies such as smart phones for extension is still uncommon.

In summary, there are three major challenges to attend to in order to improve policies to support sustainable food systems. First, governments currently rely too much on subsidies and less on incentives to achieve policy goals. Rationalising subisidies for food, water and energy is essential for sustainable intensification to be scaled out. Second, policies that improve power supply are essential to reduce costs of irrigation and ensure affordable and equitable access to groundwater for increased intensification. Finally, there is a need to better integrate with the private sector to improve food production and marketing, as well as creating a more supportive enabling environment for the private sector to do business. Small holdings, low purchasing power and small marketable surplus of most farmers in the EGP region increases transaction cost of farmers and lowers their bargaining power in both input and output markets. Aggregating smallholders into some kind of collective can reduce the transaction costs for business and improve farmers' bargaining power.

There is also a need to reimagine machine subsidies. Instead of subsidizing the capital cost of machines, which benefits only the better-off farmers, it may be more effective to offer farmers first-use subsidy for conservation agriculture equipment. Such a subsidy may encourage hesitant farmers to try out conservation agriculture and reduce the cost of experimentation for them.

8 Follow up work required under SDIP Phase 2

Results from Phase 1 provide an evidence base for improving sustainable food systems at the local scale. Farm level trials have demonstrated that CASI is a suitable portfolio of techniques that can contribute to improved food, energy and water security by improving water and energy productivity, while at the same time increasing farm level profits and using less labour and resources. Interactions with the wider operating environment also indicate the potential for these technologies to be both outscaled and upscaled, although to do this effectively requires institutional and policy level changes that support these technologies. Upscaling these results to village, district, state, national and regional levels can aid strategic planning and decision-making processes to support sustainable food systems more broadly.

In Phase 2 of SDIP, the aim is to create space for strategic longer term thinking about regional development, and help remove the policy and institutional barriers to sustainable food systems, particularly in relation to intensification, water management, mechanization services, market access and with the full participation of women. ACIAR, together with implementing partners will build on and deepen the technical and socio-economic knowledge base developed in Phase 1 to create an enabling environment for widespread adoption of sustainable food systems across the region, of which CASI technologies are a positive and practical example.

The research directions for SDIP2 are informed by the successes and failures of SDIP1, as identified by ACIAR, project members, the Project Steering Committee and an External Review team. They aim to use processes and develop capacity and products to communicate and influence policy makers in the region. Phase 2 will consider the following activities for improved food, energy and water management practices and processes that result in more sustainable food systems:

Regional Food Systems Foresight and Dialogue

- Improve collaboration between key regional partners through Foresight and Dialogue processes to strengthen understanding of longer term food systems changes, the implications for food, water and energy security and transformational opportunities, particularly in the context of gender and climate change. This will necessarily start with a synthesis of currently available information on options for transformation of food systems in the region, and identification of trends and key gaps.
- Implement Foresight work at the local level, using SRFSI's detailed location specific research results to understand changes to local systems and potential options.
- Through existing local networks, this will focus on producing the kind of information that policy and decision makers would want to see to be able to promote CASI on a wider scale. Relevant partners will be invited to join initial Foresight events to guide the development of this work at the local level.
- Build on existing farm level models (i.e. APSIM) to help understand implications for long term sustainability of CASI approaches compared to conventional practices, including for productivity, water use and soil carbon dynamics. APSIM models have been developed for each district, and for different crops and cropping systems. These models can be used to generate information on the long-term viability and risk of different techniques under different management options. APSIM modeling for future scenarios to 2030 was a strong recommendation from the SRFSI External Review Team. It would be used to generate scenarios to be developed in conjunction with a range of end-users, but could for example include the consequences of closing the yield gap using CASI compared to conventional approaches. The reviewers recommend going beyond crop yields and variability and related economic projections and include soil fertility trends, weed, pest and disease incidence and management and environmental impacts such as water and energy use, greenhouse gas emissions, pesticide use, food losses and waste management. These additional projections will be critical to gain attention and support of high level decision

makers, and a key success factor is in getting the information in the right format to be useful for decision makers.

- Build on current research outputs to better quantify water use at different scales. In addition to field scale understandings of CASI water use, this needs to be scaled to quantify the implications of intensifying production based on CASI approaches compared to conventional approaches. Bangladesh is well modeled up to the basin scale (e.g. ICIMOD, CSIRO), and so work should focus here first to determine and demonstrate usefulness for planning purposes. India is less well understood and accessing data for model verification is problematic; this will be a secondary priority.

Policy and institutional analysis

- In the context of the EGP and identified barriers to scaling sustainable food systems, understand institutional arrangements that govern information transfer; water management options under different rights and tenures; and risk management, in particular for women and other disadvantaged groups. Institutional work will include some of the groups/models that have been worked with in SRFSI to take lessons on what works. These locations will be kept as sites to link institutional and field scale work. Specific focus will be on:
    - The institutions that shape how information about new technologies, their effectiveness and profitability is transmitted to farmers, including the gender-sensitivity of different models of information transfer;
    - Alternative property right arrangements for water and how this is related to the use of other inputs; and how wider hydrological requirements might be integrated into farm-level choices through attenuating property rights. This includes how these would optimally be treated differently for different groups (e.g. landholders versus tenants; women farmers versus men);
    - Climatic and market risk and uncertainty, and the capacity of different institutional arrangements to help farmers deal with these.
- Create an 'ease of doing agribusiness' index for EGP states and countries, and use field sites to compare different locations.
- Analyse the political economy of cross border agricultural trade in Bangladesh, India, and Nepal, using rice as a case study commodity. This study will consider four levels of analysis of the rice trade: the source, the border, the point of consumption, and the institutions of influence. Such an understanding is a prerequisite to devising effective policies on farm incomes, nutrition, agricultural water use and challenges of climate change adaptation across the region.

Field level studies

- Monitoring of impacts of CASI on soil and environmental health (soil fertility, weed management, herbicide use), which can be fed back into the Foresight and Dialogue processes to help inform decision making.
- There is a major opportunity to make more progress in management of soil related issues and monitoring soil health; this has been identified by the SRFSI project team and recommended by the External Reviewer team. Important soil constraints have been identified including extremes of soil pH and associated toxicities and deficiencies; low organic carbon levels; trace element deficiencies; and soil structural problems. Options to address these issues need to be explored, and could include:
    - Continue monitoring cumulative soil health benefits that are to be expected as a result of longer-term adoption of CA practices based on international experience.
    - Investigate the use of lime and or trace elements to address soil pH barriers to economically viable crop and forage production
    - Investigate opportunities to enhance soil organic matter through better management of soil mulching
    - Emphasise the development of site specific nutrient management, particularly for rabi crops
    - Investigate the opportunities for increased emphasis on the production of biologically fixed nitrogen through greater use of legumes and pulses
- Integrated Weed Management is important from a sustainability angle, as emerging farming systems develop new and more complex weed problems. This will help avoid issues with herbicide contamination and resistance in the long term. This was highlighted as a priority by the External Review team, including the following specific activities:
    - Improved IWM through use of better seeding openers and use of cover crops and mulches
    - Continued evaluation and selection of crops and varieties with better weed suppression properties.
    - New investigations on IPM for better insect and pest control with consequently more judicious use of pesticides

Other analytical studies

- Gender
    - Gender will be integrated into all Components, and a specific focus in Foresight, Institutional and Field Level studies.
    - Explore women's role in agriculture in the EGP, including characterizing the nature and trends in women's employment in agriculture for meso level regions with the EGP. This will be linked to a qualitative understanding of the processes that drive

the shifts in gendered employment patterns in agriculture, and the policy implications of these.

- Options for improving access to CASI mechanization
    - Develop a better understanding of the machine rental markets that are critical to the large-scale adoption of CASI technologies, including development of a typology of existing service providers who can upgrade their business to efficient Custom Hiring Centres. Apply and learn from these business types to develop recommendations to improve existing equipment subsidy and targeting policies.
    - Explore value chain and policy interventions to accelerate adoption of zero tillage in rice-wheat farming systems across the Indo-Gangetic Plains of India to reduce crop residue burning and boost sustainable food, energy and water security.
    - Pilot business models for the Versatile Multi-crop Planter (VMP) business model to promote adoption of CA-based cropping intensification in Bangladesh. This project builds on a previous ACIAR project that has developed CA-based planters suitable for conditions in Bangladesh, and will work on identifying policy and adoption level bottlenecks to CA planter adoption and developing feasible commercialization models.
    - Convene the private sector for improved access to mechanization, including chamber of commerce as a linking mechanism at national/regional levels. There is scope to build off existing platforms.
- Make better use of paired locations and contrasts between SRFSI field sites, including within and between countries. Different contexts and approaches have led to variations in the uptake of CASI in different locations. The regional success of CASI requires a vehicle for sharing these lessons learned from both successful and less successful sites, and identifying best practice. This was also recommended by the SRFSI External Review team.

Further reading

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