7 An improved knowledge base to support food systems change

This chapter identifies key themes that have been explored within ACIAR SDIP, including:

- groundwater development
- the role of women in agriculture
- climate change mitigation and adaptation
- knowledge sharing mechanisms.

This work recognises that access to groundwater and the wider-scale implications of its use are critical, including interactions with energy and food security. These interactions are becoming more important as climate change impacts rainfall timing, quantity and intensity (Dawson 2019). The role of women is very variable and often not well understood. These elements are critical parts of developing sustainable food systems.

7.1 Sustainable groundwater development

The Eastern Gangetic Plains differs from other areas of South Asia in that groundwater resources are generally underdeveloped, with only around 40% of net annual groundwater availability utilised. Over 90% of groundwater currently used is for irrigation, although access is limited by high energy prices, since most farmers have had to rely on diesel pumps, although this is changing rapidly.

For smallholders in the Eastern Gangetic Plains, intensification is key to maximising profitability and productivity. Future development based on diversification and intensification requires better access and more efficient use of more water (up to sustainable limits), especially in the dry winter season when groundwater is the main source of available water.

The ultimate goal of the ACIAR SDIP program is to engage in applied research that promotes the development of groundwater resources for agriculture in a sustainable and equitable way, so that the current cost of irrigation is reduced while still working within sustainable extraction limits. The key research themes have focused on:

- options for more efficient use of water at local levels
- the impacts of these savings
- how energy and groundwater policies interact to influence agricultural production.

7.1.1 Access and availability

Initial work within ACIAR SDIP looked at the context for groundwater use in agriculture in the Eastern Gangetic Plains, both in terms of availability and access (for a summary of findings see Jackson et al. 2018). Groundwater potential and surface water availability (including tanks and river) were assessed.

Water availability

In accessing water for irrigation, there is an important distinction between availability (such as physical access) and accessibility (such as infrastructure and affordability). The International Water Management Institute conducted a temporal and spatial assessment of water available for irrigation in the 8 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 9 m below ground level.

Groundwater resources were underutilised in most of the project's study sites, and were not a constraint for irrigation. Most study districts showed groundwater tables within 9 m below ground level, which means that small surface pumps could be used to access groundwater. The exceptions are parts of Dinajpur, Rangpur and Malda. Groundwater levels fluctuate on average by 0.49 m in India, 0.36 m in Bangladesh and 0.28 m in Nepal on a seasonal basis, indicating heavier withdrawals in India followed by Bangladesh and Nepal. Temporal assessment of groundwater tables indicated significant hotspots of withdrawals likely associated with domestic and industrial activities. Apart from Dinajpur and Rangpur, these withdrawals were 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 was under cultivation for at least one season. Currently, continuous irrigation for 3 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 3 crop intensive irrigation patterns in all areas. The results show that there is potential to use groundwater resources to irrigate between 57 and 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 Eastern Gangetic Plains, 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 the International Food Policy Research Institute 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 to 10 years, and 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 low-cost pump sets from China, the capital cost of pump sets is reduced, which has allowed more widespread ownership and more competitive water markets.

Dependence on electric pumps is higher in West Bengal and Bangladesh as electricity supply in those locations is more reliable. A policy change in West Bengal in 2011 which liberalised the tube-well permit system and reduced capital costs and barriers to electricity connections for irrigation, resulted in approximately two-thirds of all irrigation pumps in the state now being run on electricity. Recently, the Government of Bihar also started a program to electrify irrigation pump sets. The number of electric pumps is targeted to increase from less than 20,000 in 2017–18 to more than 400,000 in 2022. Even if Bihari farmers pay the full cost of electricity, the hourly cost of irrigation will be one-quarter of what it is now with diesel pumps. As the flat tariff system incentivises farmers to use scarce energy and groundwater wastefully, connections should be metered, ensuring accountability and transparency.

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 behaviour appears to extend to pump renters who use electric pumps as well, despite lower pumping costs in general.

In considering policies to promote irrigation, subsidising 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 Eastern Gangetic Plains. 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 utilisation in north-west Bangladesh are due to concerted and integrated efforts and coordination on the part of the public and private sector. However, in the Indian Eastern Gangetic Plains and Nepal Terai, groundwater is underutilised due to a combination of 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.

7.1.2 Local water management options

Proving and scaling farm-level water saving technologies

From the SRFSI project, farm-level water savings have been confirmed when CASI techniques are used, with total water use reduced by 5 to 13%; and irrigation water use reduced by 11% (Gathala et al. 2020). At the same time, yields can be maintained and profit increased. Higher water savings were recorded in wheat, maize and lentil. Diversification of rice–rice systems to an alternate winter crop could have major impacts on water use. Details of local hydrology, irrigation water use and water productivity of individual crops and cropping systems are found in Islam et al. (2019).

Improving local water availability using Managed Aquifer Recharge

South Bihar is one of the most water-challenged regions in the country, having semi-arid climatic conditions. The region faces occasional floods and droughts. Seasonal water availability determines the cropping pattern, as agriculture in the region is mainly rain-fed. Ensuring reliable irrigation sources is crucial for meeting the demands of sustainable agriculture. Nalanda University explored the potential of aquifer storage and recovery techniques for supporting sustainable agriculture intensification in South Bihar. This technology helps to store rainfall during the wet season due to rainfall events or floods, and makes it available during the dry winter season. The main objective of this project was to demonstrate the technical viability of this technique and to deliver information for minimising the uncertainties in planning and design for its future use, including socioeconomic aspects of its management. Initial results have been published by Bandyopadhyay et al. (2021) and Sharma et al. (2021).

To develop an understanding of the physical, chemical, and social aspects that affect the potential adoption of aquifer storage and recovery in the South Bihar aquifer, primary fieldwork was undertaken in 2 villages in Nalanda district. Based on geomorphological parameters (for instance, rainfall, elevation, soil and aquifer characteristics, surface and groundwater quality) and socioeconomic indicators (tacit knowledge, land ownership, willingness to participate), 7 suitable sites were identified in 2 villages, Nekpur and Meyar in Nalanda, Bihar. The construction of 7 aquifer storage and recovery systems were completed in September 2020. The geophysical and geochemical characterisation of the aquifer at the installation sites showed a highly heterogeneous nature of the aquifer. In both villages, the local community had supported the team in various ways. Focus group discussion, personal interviews and socioeconomic surveys in the study area revealed the willingness of farmers to adopt and operate the new aquifer storage and recovery systems. Conversion of ‘failed bore-wells’ into aquifer storage and recovery installations emerged as a priority for farmers from the participatory discussions being promoted during the study period, since it may require construction of the filtration unit only (recharge pit) but not the actual bore-well. Overall, the project has demonstrated the feasibility of aquifer storage and recovery in both hard rock and deep alluvial aquifers in the marginal alluvial plains of South Bihar.

This study has also demonstrated an 'entrepreneurial farmers-led model'. The critical elements of this model include:

- a multidisciplinary approach to site selection in which scientific assessments can be integrated with socioeconomic insights
- system will be initially adopted by entrepreneurial farmers who agree to invest and share benefits
- co-designing the recharge pit using locally available material and ease of maintenance.

While a strong knowledge input from scientific literature ensures credibility and confidence necessary for the technical feasibility of aquifer storage and recovery, the flexibility of a participatory approach allows the farmers to creatively engage with the design and governance aspects of recharge pits. This exploratory work has generated interest for conducting long-term research on groundwater quality and quantity changes that may occur as a result of aquifer storage and recovery. There were delays in construction of the aquifer storage and recovery structures before the monsoon season of 2020 due to COVID-19 restrictions and flooding, so planned monitoring of water yield and quality implications will be ongoing after project completion.

The scaling up of aquifer storage and recovery would require significant policy support. There is an opportunity to engage with the *Jal-Jivan-Hariyali* mission of the State Government of Bihar, which is attempting an integrated approach to water resources management and environmental wellbeing. Under this mission, the state government is constructing both surface-based and groundwater-based water recharge structures. However, the mission's top-down model leaves little space for meaningful participation of local stakeholders, jeopardising both the effectiveness and efficiency of the program. The state agencies can initially adopt our design at institutional level for augmenting aquifers in selected parts of Bihar. The entrepreneurial farmer-led model builds local accountability, creates avenues for private investments, and opens space for continued innovation in technology and management while also committing to resource distribution justice and environmental sustainability. However, the model emerging from our pilot study needs further analysis; even though the initial findings are promising, the long-term viability of such projects needs to be monitored.

7.1.3 Understanding wider impacts of groundwater development through a food-energy-water lens

Governments in the region use a range of policy instruments with the intention of both increasing accessibility of irrigation, and ensuring sustainability of groundwater resources. Alternative – and cheaper – sources of energy are one option to reduce the cost of irrigation and boost access. Based on experiences in the western Indo-Gangetic Plains, many policymakers are concerned about declining water tables and the implied unsustainable use of groundwater. There is significant scope to develop sustainably intensified farming systems based on groundwater in the Eastern Gangetic Plains with the right institutional arrangements and within sustainable resource limits. Several studies have looked at the impacts on groundwater when changing one part of the system, particularly within a framework of the food-energy-water nexus. This work demonstrates that common policies for managing groundwater development do not always achieve the intended outcomes.

Understanding regional hydrological implications of on-farm water savings

Work from CSIRO demonstrates that policies that promote farm-level water savings such as those associated with CASI technologies do not always reduce overall water use or improve groundwater levels at a regional scale (Mainuddin et al. 2021). This work contributes to our understanding on how field-scale water savings impact on the local and regional water balance and groundwater recharge. When irrigation water is applied, it is common for some of it to pass below the root zone as drainage and/or run off the field. In groundwater dependent areas with good quality, shallow water tables, this drainage is not lost but rather replenishes the aquifer and is available for other users. It is suggested that the key comparisons between cropping systems options (for example, conventional agriculture versus conservation agriculture) should be based on total evapotranspiration (ET = soil evaporation + crop transpiration), not on the amount of irrigation water applied and its subsequent drainage component.

In the north-west of Bangladesh where groundwater tables are declining, the government policy responses to prevent further decline focus on more efficient irrigation. It has been demonstrated that without reducing the actual crop evapotranspiration, adoption of any water-saving technologies (for example, alternate wetting and drying, deficit irrigation, conservation agriculture) to reduce seepage and percolation loss of water will have little impact on improving the declining groundwater levels in the region (Mainuddin et al. 2020). Work undertaken in ACIAR SDIP has extended the findings to the rest of the Eastern Gangetic Plains. Simulations using the Agricultural Production Systems Simulator model indicate that in rice–wheat, rice–maize and rice–rice systems, although conservation agriculture results in a reduced amount of irrigation pumping requirement, there is very little difference in overall evapotranspiration between conventional agriculture and conservation agriculture practices. If anything, conservation agriculture is likely to result in higher evapotranspiration due to enhanced rooting and higher levels of rabi crop production. In this sense, claims that conservation agriculture will result in reduced water use and groundwater drawdown in the Eastern Gangetic Plains on a wider scale are likely to be baseless, although they will still contribute to reduced costs and emissions associated with groundwater pumping. Many water saving measures reduce the amount of water applied (which is a saving from the perspective of the farmer), but not the evapotranspiration from the field. Only measures which result in reduced evapotranspiration on the farm will save water for the region (Mojid and Mainuddin 2021). However, the farm water saving measures may include altering the source of irrigation water or the destination of water drained (by surface or subsurface drainage) from the farm, and this may have an impact at regional scale.

In a desk study of the regional water balance in several districts, it is demonstrated that there is a large excess of rain over potential evapotranspiration in the north-eastern parts of the region, and the actual evapotranspiration is likely to be close to the potential (Mainuddin et al. 2021). Conversely, there is a large deficit of rain to satisfy the evapotranspiration demand in the south-western parts. This suggests that incentive to save water at the farm scale is likely to be limited in the north-east, but significant in the south-western parts. The impact of any water saving on the regional hydrology is likely to be more limited in the north-east and greater in the south-west. There is evidence to suggest that more groundwater use could be developed in parts of India and Nepal, whereas in parts of north-west Bangladesh the use may already have reached its potential.

Links between energy and water policy

A study implemented by the International Water Management Institute (Mukherji et al. 2020) shows that the impacts of groundwater and energy policy reforms have had a much lower than intended impact on water use and agricultural productivity and profitability in West Bengal, India. Over the past 2 decades, the state has undertaken 3 important policy reforms related to groundwater and electricity:

- Universal metering of electric-run agricultural tube wells starting in 2007.
- Change in the groundwater law in 2011, which removed the requirement of farmers having to procure a prior permit from the groundwater department to get an electricity connection.
- Provision of a capital cost subsidy for the electrification of groundwater pumps in 2012.

These 3 policy measures helped remove barriers to the electrification of agricultural wells and tube wells. This resulted in a more than threefold increase in the number of electric pumps – from 86,776 in 2007 to 303,018 by 2018. In this study, the impact of the increase in the number of electric pumps on agriculture- and groundwater-related outcomes was analysed using government (block-level) data and community inputs.

It was expected that electrification of wells and tube wells would affect agricultural and groundwater outcomes through lowering the costs of irrigation, as had happened in other states in India. Per unit costs of pumping groundwater with electric pumps is much lower than pumping with diesel pumps. Therefore, it was expected that farmers with access to electric pumps would operate their pumps for longer hours and grow more water-intensive crops. However, despite the positive effect of the groundwater policy reform on the immediate outcome in terms of the number of pumps electrified, the effect on agricultural outcomes such as cropping pattern, cropping intensity, cropped area, production and yield was not evident. There was a positive effect of the policy on the summer (boro) paddy area and production, and a negative effect on the area under pulses. Yet, these effects were not robust and were found only in a limited number of blocks. It was found that groundwater policy changes led to slight improvements in groundwater levels in the period after 2011, as compared to the period before. The expectation was that groundwater levels would decline further, but given that cropping patterns and crop water use had not changed significantly in the post-2011 period, there was no overall acceleration in the pace of groundwater extraction either.

This work demonstrates that common policies for managing groundwater development do not always achieve the intended outcomes. Farmers reported that the reasons they had not increased or diversified production was mainly because during the same period, profit margins had declined; electricity and other crop input costs had increased, while prices received for their crops had stayed the same. These results from West Bengal show that energy and water policies need to be made in collaboration with agriculture and food policy if they will be successful in sustainably increasing food production.

Quantifying sustainable water yields and their interaction with food production

At different locations across the Indo-Gangetic Plains, an assessment of the trade-offs between physiologic, economic and sustainable water yields has been undertaken for rice, maize and wheat (Gaydon et al. 2021). Water resources are generally underdeveloped throughout the region, and an assessment undertaken now allows adequate time to plan for the sustainable development of groundwater resources.

Quantifying sustainable water yields and their interaction with food production shows that physiological crop yield gaps are greater in the Indo-Gangetic Plains, and confirms there is opportunity to increase use of groundwater in some locations with the right mix of crops and farming techniques. There is a clear trend for over-exploitation of groundwater in the western Indo-Gangetic Plains, and underexploitation in the east. Modelling allows us to look at different crop and farming system combinations to find the most appropriate mix for both productivity, groundwater sustainability and economic returns.

For the vast majority of the Indo-Gangetic Plains, the real measure of sustainable irrigation is a balance between evapotranspiration and groundwater recharge. A simplistic assumption in the context of a groundwater overexploitation of (for example) 30%, is that decreasing irrigation pumping by 30% will bring it into sustainability. Simulations show, however, that a reduction by 30% in Haryana will decrease evapotranspiration by less than 10%, and that to achieve an actual reduction in evapotranspiration of 30% would require reduced pumping of over 50%, a rice yield reduction of around 50%, and even greater decreases in economic returns to farmers. Alternative options include different cropping patterns in combination with water conservation measures and would be more appropriate in addressing multiple constraints such as productivity, profitability and water management.

Farmers in the Western Gangetic Plains operate closer to the physiological potential yield for major crops, whereas farmers of the Eastern Gangetic Plains have greater physiological yield gaps and greater potential to increase their current crop yields. Cropping districts in the Western Gangetic Plains currently overexploit groundwater resources and are farming unsustainably with their current cropping practices, whereas the examined Eastern Gangetic Plains sites in India and Nepal are underexploited. This, together with current yield gaps, strongly suggests the possibility of shifting key crop production in India (particularly rice) eastwards into the north-eastern states in the future. Analyses have shown that even with increased fertiliser and irrigation application (bridging physiological gaps), cropping systems in many sites in the Eastern Gangetic Plains would still not be overexploiting their groundwater resources; Bangladesh is an exception to this.

It also calls into question the current focus on crop diversification in the Eastern Gangetic Plains, and asks whether the Eastern Gangetic Plains is not better suited to carry a large load of India's rice production – with more crop diversification (less water-intensive non-rice cropping) to be encouraged in the currently over-exploited Western Gangetic Plains. Analyses for Karnal (Haryana) in the Western Gangetic Plains indicate that modifying the current rice–wheat system to (40% rice:60% maize in kharif) followed by 100% wheat in rabi is both sustainable and profitable for the region. India needs that missing 60% rice to be grown somewhere, however.

Electricity subsidies have a significant effect on farmer profitability in the Western Gangetic Plains, but the effect of these subsidies decreases with less rice in the system, due to decreased groundwater pumping for example, when substituting maize for rice to achieve sustainability. Analyses were conducted at all sites on how sensitive the 'maximum economic yield' for major crops was to:

- cost of nitrogen
- cost of irrigation
- price of grain.

We found that variation in the selling price of grain was the greatest influencer of a farmer's profit, and hence a key determinant of the economic yield gap. Variation in the cost of irrigation and the cost of fertiliser were similar, and both considerably less than grain price impacts – across all sites west to east in the Indo-Gangetic Plains.

Learning from past development patterns in West Bengal and Bangladesh

The study of agrarian change in Bangladesh and West Bengal has a long history spanning several centuries. The region has experienced periods of high agricultural growth, and others of poverty and famine. The trajectory of agrarian growth in 2 countries – with the same agroecology, history and culture, but with 2 different policy settings, became a topic of intense interest among scholars of agrarian change. A book comparing agrarian change in Bangladesh and West Bengal from 1970s to mid-1990s concluded that West Bengal had better growth rates than Bangladesh due to agrarian reforms. However, since the mid-1990s, it is clear that Bangladesh has experienced higher growth rates, while growth in West Bengal has slowed down and even stagnated. Recent work has explored the trends in agricultural growth since the 1990s, and analysed the reasons for these trends (Mukherji et al. 2021).

Six common themes were identified that can explain the different trajectories of agricultural growth. These include:

- the expansion in area, production and yield of boro paddy
- groundwater irrigation that has made the expansion in area, production and yield of boro paddy possible
- informal markets for groundwater irrigation services, and role of electric and diesel pumps in promoting these markets
- the rising cost of cultivation and lowering of profits from boro paddy, and move towards crop diversification
- public policies and policy discourses on water, energy and food
- groundwater depletion potentially linked to climate change.

These themes have been used to construct 2 different storylines. The first storyline is for the period of early 1980s to mid-1990s in West Bengal, and early 1980s to end 2010s in Bangladesh. During this period, both West Bengal and Bangladesh saw rapid rise in area, production and yield of boro paddy, supported by policies in water, energy and food domains that also encouraged intensive groundwater use. The second storyline is for West Bengal (from mid-1990s onwards) and Bangladesh (from early-2010s onwards). Both started experiencing stagnation in area, production and yield of boro paddy, which can be attributed to unfavourable cost of production and output price ratios. In recent years, declining groundwater tables, possibly due to climate change, is another cause for worry. Farmers are trying to diversify away from paddy, and yet, paddy remains important from a food security perspective, and diversification brings its own sets of challenges.

7.1.4 Key lessons

This work recognises that access to groundwater and the wider scale implications of its use are critical, including interactions with energy and food security. These interactions are becoming more important as climate change impacts on rainfall timing, quantity and intensity (Dawson 2019). Agriculture-related groundwater management must be incorporated as a component of any wider water-focused program.

The importance of understanding the links between local and regional hydrology

Groundwater resources are in general underexploited in the Eastern Gangetic Plains, meaning there is room for further development in many locations. However, there is variation in district-level groundwater use – even though at a state and regional level the system is in balance. Some locations have seasonal (pre-monsoon) decline in groundwater levels, which is important to monitor because we need to know whether this seasonal decline is compensated by recharge in the wet season. To cater for this variability at district levels, we need a suite of management options and policies that can be applied.

The bottom line is that hydrology matters, at different scales. While it is true that in many locations groundwater is abundant and extractions can increase, it does not take long for this to change, and coordinated monitoring efforts are required.

Identifying reasons for groundwater decline

There is a misconception that when groundwater is used for irrigation, that everything pumped from the system is lost. This is not true in places where groundwater is of good quality, as is the case in the Eastern Gangetic Plains – water that is not used by plants contributes to recharge and is used by others.

The true loss from the system is actually evapotranspiration (evapotranspiration = water taken up by plants + evaporation). Reducing farm-level water use does not reduce evapotranspiration and hence water use overall. To really save water, evapotranspiration needs to be reduced by changing cropping patterns or reducing crop duration.

Groundwater decline is a concern in the north-west of Bangladesh, and there are policies that encourage farm-level water savings to halt this pattern. However, there are multiple causes of groundwater decline, both on- and off-farm, including changes in climate, river flows and land use. We need to know what causes groundwater decline in specific locations, because if groundwater decline is driven by off-farm factors, on-farm solutions will have very limited value.

Improving access to pumps

Informal, private rental markets play a major role in ensuring irrigation access for almost all farmers in the Eastern Gangetic Plains. In a survey conducted by the International Food Policy Research Institute in 2015, only 25% of farmers owned pump sets, with 75% renting pumps to access irrigation. Water buyers are often smaller and poorer farmers. There is considerable heterogeneity across water users and one policy won't work the same for everyone. A subsidy on pump ownership for example, will likely benefit those who traditionally own pumps (men, larger farmers) but does not guarantee any welfare gain for others (women, tenant farmers).

Better targeting of support could produce multiple, integrated benefits. For example, subsidising access to pumping technologies for those more likely to sell water into groundwater markets is a better option than a universal subsidy if the aim is to lower the cost of water access.

The changing energy water nexus

When groundwater is used, energy and irrigation are closely tied together, and energy costs and access can influence the amount of water pumped. The energy–irrigation nexus is changing in the Eastern Gangetic Plains, with rates of rural electrification increasing rapidly. Despite this, large-scale electrification in West Bengal has not led to the majority of farmers greatly increasing the amount of crops they produce (especially boro rice), or changing the kinds of crops they grow. However, at the district level (for example, in northern West Bengal) there were impacts in locations that previously did not have access to electricity. Because of this, groundwater levels have remained stable.

We know that grid electrification is happening rapidly in the Eastern Gangetic Plains. What tariffs and power supply arrangements will improve agricultural development? And if we get that right, what impact will it have on local and regional hydrology? These questions remain key to sustainable groundwater development in the future.

Water alone is not enough

Improving access to water alone is not enough to increase development; farmers also need access to inputs, stable output prices and better market infrastructure to improve productivity and profitability. Addressing development challenges must go beyond 'just adding water'.

Agricultural development in the Eastern Gangetic Plains is tied to groundwater. In Bangladesh, agricultural growth that targeted national food security began once groundwater restrictions were removed. In West Bengal, the target of groundwater preservation has resulted in a focus on diversification. This has resulted in lower levels of development in West Bengal in the past decade.

Within India, given the serious levels of overexploitation of groundwater in the western Indo-Gangetic Plains, there is the potential for rice production to be shifted to the Eastern Gangetic Plains. This makes sense from a hydrological perspective, but what would it take for that to happen sustainably? There are limits to the traditional ways of promoting groundwater development. Water and energy policies need to be made in collaboration with agriculture and food policy if they will be successful in sustainably increasing food production among farmers.

7.2 Understanding the role of women in agriculture

Gender is a cross-cutting theme for the SDIP, which required the 7 SDIP partners to integrate the gender context within all interventions and to embed it within their institutional approaches. ACIAR SDIP explored the variations in spatial and temporal pluralities with respect to gender in agriculture within the Eastern Gangetic Plains and found it shaped by the cultural roots and economic status of the respective countries, regions and sub-regions. Recognising the gendered dimensions of the water, energy and food sectors and nexus, and the disparities in the agency and engagement of women and men, ACIAR SDIP framed projects to allow gendered data collection and aimed for gender equity or women-positive implementation. A review of the macro and micro factors impacting on gender outcomes within the Eastern Gangetic Plains contextualises the various pieces of work, and assists in assessing outcomes and forming recommendations.

Key themes around gender that emerged from the ACIAR SDIP program work include:

- understanding the context for women's engagement in agriculture, including the trends of feminisation and defeminisation
- ensuring participation in research activities
- identifying the impacts of farming system change for women
- using experiences to inform a scaling paradigm and priorities for future work.

All references in this section are reports and publications produced within ACIAR SDIP.

7.2.1 The big picture for women in agriculture

Mapping the spatial variations in gender vulnerabilities at sub-regional levels in the Eastern Gangetic Plains provides a backdrop to understanding changing gender roles in agriculture (Sen et al. 2019). The report on *Understanding Women's Role in Agriculture in the Eastern Gangetic Basin* showed that work participation rates of women in the rural Eastern Gangetic Plains demonstrate both considerable regional variations and diverging trends over time, defying its relatively small size and the shared agricultural and economic characteristics of the basin. Within the region there is also a high incidence of male-selective out-migration, which is known to impact women's work, and spatially embedded physical and cultural pluralities. The report concludes that there is a pre-existing rationale for expecting intra-regional variations in women's role in agriculture within the region, that is likely to be shaped by complex intersecting factors, necessitating a comprehensive understanding of the region from both macro and micro perspectives.

Patterns of feminisation and defeminisation

The term feminisation of agriculture refers to the gendered nature of agrarian transitions under conditions of rapid and globally interconnected socioeconomic change (Darbas et al. 2020). The increase of female involvement in agriculture has been attributed to male labour out-migration in the face of persistent rural poverty, growing numbers of female-headed households, and an increase in labour intensive cash cropping on both family and corporate farms. Much of the primary fieldwork-based literature assumes feminisation as a temporal trajectory in South Asia in general and the Eastern Gangetic Plains in particular, especially as a consequence of increased male out-migration. The macro-level data published by government sources in Nepal and Bangladesh reveals workforce feminisation processes do seem to be occurring in both regions. At the sub-regional level, almost the entirety of Bangladesh Eastern Gangetic Plains is feminising, which conforms to the macro trends. The Terai part of Nepal is feminising, which is where the majority of workforce in the country is concentrated. However, in India, West Bengal reveals a mixed picture, while Bihar is almost entirely defeminising. There is a consistent pattern of defeminisation, both in absolute and relative terms, in spite of significant male-selective out-migration, which raises questions about defeminisation processes emanating out of economic progress. The status briefs published by the foresight component (Joshi et al. 2019; Sen et al. 2019) found a lack of comprehensive discourse on the processes behind feminisation in the Eastern Gangetic Plains belonging to Bangladesh and Nepal, or the drivers of defeminisation on the Indian side

(West Bengal and Bihar). Sen et al. (2019) provide the following explanations based on analysis of macro-level and micro-level data.

Women's labour force participation

Sen et al. (2019) found that in terms of levels of work participation by women, Nepal has a high base, while Bangladesh and India started with a much lower base. Over time, both Nepal and Bangladesh have had a feminising rural and agricultural workforce, the latter more sharply so. However, Joshi et al. (2019) suggest that the quality of work and wages have not sufficiently improved for the women in these 2 countries, and at a few sub-regional contexts have actually deteriorated. The foresight briefs analysed the data on the Indian Eastern Gangetic Plains, which has defeminised steadily over the last 30 years, with some reversal in the last 3 years to 2015. The report by Joshi et al. (2019) shows that in rural India, the engagement of women in agriculture has decreased from 36% in 2004–05 to 21% in 2015–16, and the women's labour force participation rate has also declined from 50% in 2004–05 to 25% in 2017–18. Simultaneously, the share of women who are out of the labour force has increased from 51% in 2004–05 to 67% in 2015–16. It uses the nationally representative dataset National Family Health Survey to predict the labour force participation of sample women in rural India based on 16 demographic and socioeconomic variables. Sen et al. (2019) noted that the rate of unemployment among women has risen at a rate far exceeding that of men, suggesting that of the women going out of work, many still seek it. Both reports find the pattern of defeminisation to be somewhat counterintuitive as all the potential characteristics typically linked with feminisation – like low agricultural income and male out-migration – exist in the region.

Joshi et al. (2019) provide some insights into factors affecting labour force participation. In India, poorer women have dropped out of work faster than women from better-off households, which, coupled with high unemployment rates, is indicative of a distress driven process. Education and labour force participation have a 'U-shaped' relationship: women with median levels of education (7 to 10 years) are the least likely to work, which means that wealthy educated women and poor uneducated women have the highest labour force participation. The combination of wealth and education matters in determining women's labour force participation. However, workforce participation rates have reduced faster for the poor than the rich and the relative unemployment rate (females/males) in Eastern Gangetic Plains India has gone up over the years. Women are still in the labour force looking for work, which would not have been the case had it been primarily a case of either prosperity- or education-induced withdrawal.

Joshi et al. (2019) also note that working women face higher chances of domestic violence, likely due to unobserved sociocultural norms. Women who are out of the labour force have a greater number of young children (less than 5 years of age), and also have lower levels of autonomy and mobility outside the house. Women whose husbands have out-migrated are less likely to be working than those who are living with their husbands, which challenges the normal assumption that out-migration leads to increased labour force participation for women. A defeminisation process linked with higher levels of unemployment is indicative of distress and is suggestive of displacement from jobs or lack of jobs that women can take up along with care work. In the last decade, due to an increase of unemployment among men in both rural and urban areas, male migrants have been coming back to increasingly impoverished agriculture as cultivators, leading to a decline in the share of women cultivators (Joshi et al. 2019). In the last 3 years, there appears to have been a reversal of the trend of defeminisation in Indian Eastern Gangetic Plains, though it is impossible at this stage to conclude that this reversal is of a long-term nature.

Sen et al. (2019) conclude that the recent increase in participation of women in agriculture in Bangladesh as a response to long-term male migration challenges the social norms in the country, and this could thus initiate a lasting change in the gender relations observed historically there. The stark improvement of gender gaps noted in multifaceted aspects during the last decade in Bangladesh is very likely a harbinger of this path. The feminisation process in Nepal, in contrast, is a continuation of its societal historicity, unlikely to bring about deeper changes in the gender relations in the region from the way it is now. The inability to run the rural economy without women, in a region that experienced years of traditional male out-migration, arguably shaped this historicity of social norms that found women working in the agricultural fields or their presence in public spaces acceptable. The relatively high gender gap in literacy rates in Nepal is a case in point, which indicates that the high participation of women in agriculture in Nepal is probably more functional than part of an all-encompassing pathway towards gender equity.

Contextualising the Gender Vulnerability Index

Sen et al. (2019) used selected gender gap criteria that includes the child sex ratio, relative literacy rate and relative work participation rate, showing gender vulnerability as a whole to define the Eastern Gangetic Plains region. The spatial variations of these variables indicate that the gender space of the Eastern Gangetic Plains is very often shaped by both cultural roots and the economic status of the respective country. The performative aspect of gender in particular often tends to be shaped by the latter over time, though the rules of patriarchy in the different spaces provide its initial context.

There is a clear regional difference in the levels of the 3 variables, both spatially and temporally. In the terminal period, Bangladesh and Nepal are seemingly at par with respect to the relatively high child sex ratio, Bangladesh far exceeding the status of the other 2 countries vis-à-vis relative literacy rates, while Nepal performs the best in terms of relative work participation rates. India falls behind in all 3 indicators.

In terms of improvement in the Gender Vulnerability Index over the decade that the study considers, Bangladesh is far ahead of India and to some extent, Nepal (Raju et al. 2016). Though the study comes up with broad regional patterns, there are significant sub-regional differences in both Nepal and Bihar. India's case, particularly with respect to Bihar, is worrying as the high gender gaps in most indicators have further widened, leading to an exceedingly low Gender Vulnerability Index in the latter period. The defeminising trend of agriculture in particular, and rural work in general, needs to be contextualised in the perspective of a declining status of women in India. The study also noted that the regional plurality of patriarchies leads to qualitatively different outcomes in terms of the type of roles women undertake in agriculture, in addition to the magnitude of their participation.

As previously noted, the main driver of the defeminisation process is usually agrarian distress. The influence of changing cropping patterns, the transformation of land uses, increasing mechanisation, along with effects of remittances following male out-migration, are all negatively impacting the feminisation process. There has been an increase in the incidence of unpaid work, along with feminisation in Nepal and particularly in Bangladesh, and a shifting burden of feminisation in Nepal to the elderly women (due to increased out-migration by young couples). Bihar is defeminising, in spite of being a state with high male out-migration. The returned remittances, though meagre, often offer a choice to women not to join agricultural work that pays little and requires long hours. This cannot be termed as the 'prosperity-induced withdrawal' as commonly suggested in the literature, but a slight widening of choices responding to an unfavourable labour market.

Macro and micro constraints to agricultural development

There are major socioeconomic constraints confronting all Eastern Gangetic Plains smallholder and tenant farmers, including those headed by females, including:

- Small and fragmented land size: Small input requirements, little purchasing power, small marketable surpluses, and difficulties in identifying appropriate technologies and ensuring that small farms can access them.
- High rates of poverty: Connected to the social structures of class, caste and gender. These axes of inequality mediate access to irrigation, a core prerequisite to agricultural growth and intensification in the region, which are compounded by high prices and land fragmentation.
- Food security: Entangled with caste and tribal identities and their relative socioeconomic status within (rapidly eroding) strict social hierarchies.
- Landlessness: Tenants struggle to deal with absentee landlords or negotiate reasonable terms for renting or sharecropping land.
- Poor infrastructure: Poor connectivity makes the cost of doing business in the region even higher.
- Low productivity and high costs.
- Geographic disadvantages.

An extensive scoping study of female heads of household early in the program was completed in a number of districts throughout the Eastern Gangetic Plains (Brown et al. 2020). Male out-migration affected more than 50% of those surveyed, and very few respondents had title to their land apart from those in Nepal (20%) and East Champaran (30%). About 25% of respondents had no easy access to a bank or held a bank account. There were few animal or domestic assets, and farming assets were limited to spades, shovels and sickles. About 16% of households owned an irrigation pump and the occasional chaff cutter. However, 33% of survey respondents belonged to a self-help group, which has potential benefits in terms of increasing bargaining power.

Land tenure and irrigation

Groundwater management, including access, availability and use, is a critical element in the nexus between the food-energy-water sectors within agricultural production and land management strategies throughout the Eastern Gangetic Plains (Brown et al. 2020). This is especially true for women farmers and women-headed households, where more limited social networks and gender ideologies can be constraining in traditional settings. Male out-migration has undermined the functioning of many irrigation management institutions, and persisting limitations on women's engagement has failed to counterbalance these changes. Improving access to, and the affordability of, groundwater-based irrigation is necessary to boost agricultural production in the Eastern Gangetic Plains. Potential solutions to improve the access of small and marginal farmers, and especially women cultivators, include short-term options such as innovative models of collective land and water management. This may include collective leasing or a user group approach to tube well management. In the long term, radical redistributive land reform – or, at least, clarification and improvement of sharecropping rights – is one of the few options in regions such as Bihar and Nepal.

Institutional arrangements

The 'Institutions to support intensification, integrated decision making and inclusiveness in agriculture in the Eastern Gangetic Plains' project is looking specifically at women's preferences for institutional arrangements related to water markets, knowledge transfer and risk management, and a comprehensive survey has been developed to capture these from 2,000 farming households. The survey includes a specific component that teases out the empowerment of women. Coupling this information empirically with the other data gathered in the primary survey (for example, insight into preferences for knowledge transfer), including households' ratings of policies and delivery institutions, has the opportunity to explain the link between different institutional settings and women's wellbeing.

These results will be updated based on their final reporting.

7.2.2 Approaches to engaging and assessing benefits for women

Between 2014 and 2018, the SRFSI project trialled CASI technologies with smallholder farmers in 8 districts of the Eastern Gangetic Plains. In line with the project's aim to be gender-inclusive, there was a concerted effort to mainstream gender in all project activities. The project utilised 3 main strategies to engage females as cultivators. First, prompting gender mainstreaming of (project funded) extension services with a 30% quota for female participants in all project activities. Second, development of female entrepreneurs as part of improving value chains. Third, partnering with NGOs proficient in socioeconomic mobilisation of resource-poor rural females (Darbas et al. 2020). All project data was gender disaggregated. The approach to ensuring women's participation included:

- Awareness of gender was increased through formal training, as was the importance of incorporating gender aspects in all components of the project. 'Gender Focal Point' positions were assigned in each location.
- Mainstream project extension services for farming women with a 30% quota for women participants in all project activities.
- All project activities included men and women, with participation monitored.
- All districts used protocols for gender activity reporting and templates.
- The impacts of farming systems change was monitored for both men and women in farming households.

While the SRFSI project was conscious of achieving a parity in the participation men and women, some activities such as training, workshops and focus group discussions need more deliberate gender mainstreaming efforts. Overall, women's participation rate culminated with above parity level, however, female participants were mostly engaged in scaling-out activities but not in other activities. In future projects, there will be a need to focus gender mainstreaming efforts across all activities and project sites.

In other components such as foresight and institutions, research considered the context for women and the impacts of change. For example, the foresight component contributed an understanding of the context for women's participation in agriculture, including identifying the drivers behind the trends. Training was provided to mainstream gender in food systems research, the use of mixed methods for research, and different tools and techniques that can be used to conduct participatory foresight for food exercises with communities. In West Bengal, local-level studies focused on changes due to mechanisation, and the impacts at the community level with a particular focus on women and youth.

7.2.3 The impacts of farming systems change on women: gender positive outcomes

The SRFSI project has introduced, tested and promoted CASI-based technologies which can reduce inputs (labour, water, seed) while improving profitability and maintaining yield (see **Chapter 6.1.1**). The SFRSI project worked with multi-stakeholder innovation platforms to improve coordination between farmers and agricultural agencies, and to develop conservation agriculture business models. Increases to gross margins using CASI compared to conventional agriculture practices were experienced by both male-headed 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.

Changes in farming systems impact men's and women's assets such as land, time, labour, and extension services differently, so gendered data collection is an essential component of research. A project on weed management in the Eastern Gangetic Plains focused on gender outcomes from the uptake of zero-tillage technologies (Brown et al. 2021; Gartaula and Suri 2021). Weed control is considered the biggest challenge to CASI adoption, with perceptions about the impracticability and workload implications of adoption being significant barriers. It is hoped that the time saved by adopting CASI will have significant impacts on women's time allocation, with freed time available to engage in other income generating opportunities if desired. However, other research has indicated that where herbicides are too costly to purchase, the extra labour required for weeding with CASI technology can lead to an increased labour burden for women (Brown et al. 2021; Gartaula and Suri 2021).

Semi-structured and in-depth interviews were conducted in households adopting the technology in the Eastern Gangetic Plains. The findings from these suggested that zero tillage aligns positively with reduced time burdens with no reallocation of roles or burden when herbicides are used; and that substantial time is saved, on balance more so for women. However, spray tank weight and design make the spraying of herbicides less feasible for female use, which could have further implications on gendered labour allocations, especially for rural migrant households where women are in charge. These findings suggest that on balance, zero tillage is women-friendly and inclusive and should be supported by governments, not just because it has agronomic and economic benefits, but because it can also enable equitable development. It produces time savings, no reallocation or increased burden of roles and responsibilities on women, and balanced spousal knowledge of weed management practices. Herbicide use as part of a CASI system enables diversification (both agricultural and livelihood), which emerges from saved time and money. These may have substantial impacts for zero tillage using households that enable livelihood transformation towards many of the sustainable development goals.

7.3 Promoting climate smart food production systems in the Eastern Gangetic Plains

Climate has been an overarching priority for SDIP as a whole. ACIAR SDIP contribution to improved resource use efficiency and climate smart production systems in the Eastern Gangetic Plains includes a multi-scale understanding of the situation, from farm-scale to regional levels. The likely future trends in climate and implications for agricultural production have been synthesised. Extensive on-farm trials tested sustainable farming systems and considered their performance in terms of climate change mitigation and adaptation. The performance and mitigation potential of conservation agriculture-based approaches were modelled under different climate regimes to consider performance over the long term. The practice changes tested also have positive impacts on soil health in terms of the amount and types of carbon present, and improved soil structure. At the same time, these climate smart farming systems can be profitable for farmers and local businesses, creating new employment opportunities for women and rural youth. The work of the program has contributed to a better understanding of climate change impacts through synthesis of the likely trends and their implications for agricultural production at the regional level. Several reports and publications contain details of the work around climate impacts (Dawson, 2019; Gathala et al. 2020; Gaydon et al. 2020; Jackson et al. 2019).

7.3.1 Climate change trends and impacts on agriculture

Over the past 50 years, changes to the climate of the Eastern Gangetic Plains have already been documented. Annual mean temperatures have increased by around 1°C, and the number of extreme heat days has increased while extreme cold days have decreased. There has been a slight decrease in annual precipitation and rainfall intensity has risen. These have influenced optimal planting times and the cropping season length, which have shifted through time (Aryal et al. 2019). Over the next century, climate change will adversely impact the agriculture sector in South Asia, jeopardising food security and rural livelihoods. The information summarised in this section is reported in full in Dawson (2019), in a report commissioned to synthesise likely climate projections and their influence on agriculture in the Eastern Gangetic Plains.

By 2050, average annual temperatures are projected to be between 1°C and 1.5°C higher than the 1980–2010 average; by 2100, temperatures will be 2.5°C to 4°C+ higher, with warming more pronounced in winter and for night-time minimum temperatures. The number of extreme heat days will rise twofold or threefold, and the number of extreme cold days will fall by a similar amount. Although trends in annual average precipitation are less certain, the average of all models indicates that total rainfall will increase slightly (up to 10% by 2050), with most of the increase to occur during the summer monsoon months. This increase in the summer monsoon will occur at the expense of winter rainfall, with an increased risk of drier winters. Rainfall intensity will increase, in particular during the summer monsoon. In line with temperature increases, evaporation and evapotranspiration will rise by 5 to 7% by 2050, which will likely offset the projected precipitation increases. Floods and droughts will increase both in frequency and intensity, contributing to more extreme climate variability on a year-on-year basis. River flows will be lower in winter and late spring/early summer, and higher in early spring/late summer.

The changes that will occur to the region's climate will impact the agriculture sector in a variety of ways, both positively and negatively, although the cumulative effect will most likely be negative. The most immediate threat to agricultural production is due to the increased incidence of extreme weather events, including extreme heat, droughts and floods. Underlying changes to average mean temperatures are the most significant threat in the long term and will push many regions beyond optimal growing conditions and reduce growing season length, particularly during the rabi (winter) season. As a result, grain yields are expected to fall 10 to 15% by 2050. By late century, many areas of the Eastern Gangetic Plains will be unsuitable for grain production at all. Although elevated atmospheric CO_2 concentrations will boost crop growth rates and yields, primarily for C3 plants (for example, maize), this may result in negative effects such as a lower nutritional content of crops. These interacting impacts will have a devastating effect in a region where many people are already malnourished. Pest and pollinator regimes will also change, affecting crop growth cycles, but the net impact on crop yields remains uncertain.

Targeted research on the impact of climate change on Eastern Gangetic Plains agriculture remains limited and needs to be significantly increased, especially in relation to crop heat resilience, changes to insect pest/pollinator regimes, and crop responses to elevated CO_2 concentrations. Farmers and policymakers alike need climate smart, profitable production systems that can help them deal with climate variability, and maintain food and nutrition security.

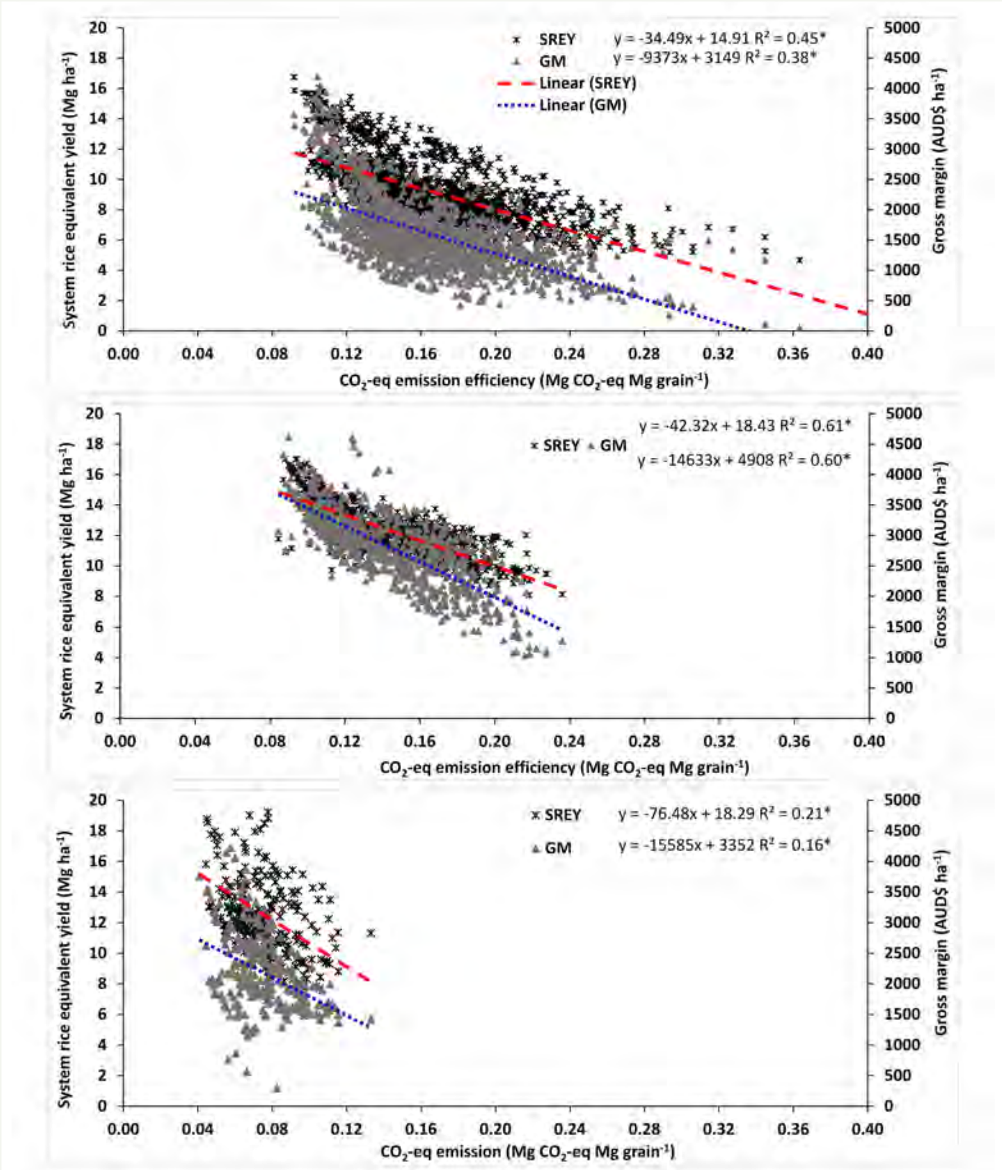
7.3.2 Promoting conservation agriculture for mitigation and adaptation

As well as being impacted by the changing climate, the agriculture sector is a significant contributor of emissions, and hence management practices that can minimise emissions and prevent the loss of soil carbon are important considerations in minimising wider scale impacts. Options are needed that can help farmers build resilience to climate change and mitigate emissions while at the same time maintaining or improving food security.

Reducing indirect on-farm emissions

CASI approaches contribute to climate mitigation by reducing fuel inputs (such as for mechanised soil tillage and pumping for irrigation), minimising tillage and improving soil carbon levels, while maintaining or increasing productivity. CASI-based systems build resilience to climate change and are demonstrated to reduce the emissions footprint of food production systems in the Eastern Gangetic Plains by 6 to 18% (Gathala et al. 2020). Indirect emissions reductions associated with production inputs vary by cropping system (for instance, for individual crops, CASI techniques reduce emissions on average by 14% for wheat, 10% for maize, 18% for lentil and 8% for rice), and so any changes to the cropping system can have wider impacts on the carbon intensity of the agricultural sector.

Figure 8 shows the relationship between yield, income and energy intensity, clearly demonstrating that with lower levels of energy inputs, higher yields and profit can also be achieved (Gathala et al. 2020:11). Similar work on intercropping of maize with leafy vegetables such as potato, peas, spinach and red amaranth showed that these systems were always more profitable than sole maize, although requiring higher energy inputs, which were offset by higher yields (Tiwari and Gathala 2017).



Note: (A) rice–wheat systems; (B) rice–maize systems; (C) rice–lentil system in the Eastern Gangetic Plains, South Asia. Values in parentheses show the total number (n) of data points; **significant at p = 0.01 level.

Figure 8 System rice equivalent yield and system net income plotted against system specific energy across districts and tillage options under different cropping systems

There is potential for significant impact if CASI systems are adopted widely; for example, increasing the use of CASI to 20% of the area of rice, wheat and maize systems in the Eastern Gangetic Plains would increase productivity by almost 2 million tonnes, generate more than AUD2 billion in additional farm profits, reduce irrigation water use by over 2,000 gigalitres, reduce energy use by over 12 petajoules and reduce carbon emissions by over 740,000 tonnes of CO_2-e.

Modelling the effect of future climate change scenarios

Using the APSIM model that was validated at 10 locations in the Eastern Gangetic Plains during the SRFSI project, further modelling explored the effect of future climate change scenarios on crop production and greenhouse gas emissions under a range of conventional agriculture and conservation agriculture management interventions (Gaydon et al. 2020). The findings suggest that in the future, the general trends are for increased rabi crop yields (maize and wheat) and slightly reduced kharif rice yields under conservation agriculture practice compared with conventional agriculture. Yields for rabi season crops (wheat and maize) tend to decrease with harsher climate scenarios and with increasing timeframes. However, wet season rice yields exhibit the opposite trend and are predicted to increase in future years, primarily as a function of increased CO_2 fertilisation, which overshadows any losses due to increased temperatures and shorter seasons. This is under the assumption that irrigation water can meet any rainfall shortages. Purely rain-fed crops would likely also be challenged by rainfall variability, which will increase in the future (Dawson 2019).

Simulated emissions were reduced by around 24% by employing conservation agriculture technologies in the rice–maize and rice–wheat cropping systems, averaged across the SRFSI sites using historical climate data. This represents emissions due to plant-soil-fertiliser residue processes in the field only. A changing future climate slightly reduces the benefits from conservation agriculture, with historical, 2050, 2070, and 2090 climates revealing a 20 to 24% benefit. There was no particular protective effect on future grain yields of conservation agriculture under climate change, compared to conventional agriculture. The yield gains from implementing conservation agriculture technologies in wheat under historical, 2050, 2070, and 2090 climates (averaged over all SRFSI sites simulated) ranged from 6 to 2%, and illustrate a declining value of conservation agriculture on yield as the climate became harsher. Maize follows an opposite trend, ranging from 1 to 4%. The full report is by Gaydon et al. (2020).

Improved resilience to climate variability

Climate change will affect temperature and rainfall patterns in the Eastern Gangetic Plains. This includes delayed onset of the monsoon, which can prolong harvest dates and hence the planting of dry season crops. The effect of planting date on wheat and lentil yield was examined using data from long-term trials. Yield reductions were recorded for wheat and lentil, including 22 kg per day for planting wheat after the start of December, and 62 kg per day for planting lentil after 15 November. This pattern of yield reductions with later sowing was supported by APSIM modelling outputs, with variability between sites and crops captured (Gaydon et al. 2020). An excel-based decision support tool was developed based on this modelling to allow extension agents to compare rabi crop options as a function of location, management (conventional agriculture or conservation agriculture) and date of sowing opportunity (Gaydon et al. 2020). This kind of information is important under proposed climate change scenarios to maintain optimal planting dates, and to help farmers make decisions about which crop to plant in the dry season to maximise yield and profit.

Improved soil health

CASI systems have a positive impact on both the amount and types of carbon present in the upper soil layers. Soil organic matter is crucial for soil fertility, water retention and maintenance of crop productivity (Awale et al. 2017), and is heavily influenced by management practices such as tillage, residue retention and fertiliser regimes. Impacts on soil carbon have been monitored within the life of the program, with CASI systems appearing to have a positive impact on both the amount and types of carbon present in the upper soil layers. However, changes in soil organic carbon are often variable in the early stages of using conservation agriculture techniques, and stronger trends are often only seen in the longer term. This is supported by modelling results which show potential for 150% increase in soil organic carbon over a 35-year timeframe.

7.3.3 Avoiding emissions through better resource management

Work from the University of Queensland has contributed to a more nuanced understanding of the impacts of sustainable intensification on emissions, in line with the SDIP overarching goal of working to address the impacts of climate change.

Ongoing work is focusing on more comprehensive accounting of emissions for conservation agriculture versus conventional agriculture systems to quantify the impacts of different crop management techniques on systems-related emissions. This includes combining input-related emissions (measured at the farm scale), direct emissions (modelled) and emissions related to residue management pathways (to be calculated), to give a more complete set of emissions for cropping systems in the Eastern Gangetic Plains. A better understanding of nitrogen use efficiency for conservation agriculture and conventional agriculture is also being explored, including the impacts on emissions, productivity and soil acidification rates.

A major strategy to halting acidification is better management of nitrogen fertiliser use efficiency to ensure minimum losses from the system. As noted in **Chapter 2.3.2**, efficient use of nitrogen fertiliser will have a positive greenhouse gas impact, and that in the long term this may be more important than the carbon dynamics in the system. Future studies should consider the greenhouse gas impacts of improving nitrogen use efficiency, both in terms of reducing the amount of nitrogen applied, hence reducing emissions associated with nitrogen fertiliser manufacturing, and the amount of nitrogen lost from the soil. Additionally, studies should also consider the greenhouse gas impacts of the remediation approach. For example, remediation measures (applying lime to soils) to overcome acidification developed through poor nitrogen fertiliser management would result in a very poor greenhouse gas outcome.

Focused work on groundwater, as reported earlier, offers an option to improve climate change adaptation and resilience, given likely impacts on rainfall timing, quantity and intensity. At present, groundwater in the Eastern Gangetic Plains is an underutilised resource, and so a better understanding of availability and the implications of its management alongside energy and food policies is critical to maintain sustainability.

Interacting policy drivers for resource management

Avoiding future emissions from different parts of the agricultural system may have more potential impact in the long run than building soil organic carbon, as this by its nature reaches a new equilibrium after which no additional gains can be made. Reducing emissions associated with residue burning and better management of nitrogen use efficiency are pathways that can have positive benefits in the future.

Rice-based cropping systems result in a high level of crop residue after harvest that must be managed before a subsequent crop can be grown. Across India, around 90 million tonnes of crop residues are burnt annually, with rice (43%) and wheat (21%) straw both major residue sources (Bhuvaneshwari et al. 2019). Much of this occurs in the north-western Indian states of Punjab and Haryana, within the narrow timeframe available for planting the subsequent crop. Burning of crop residues emitted 141.15 megatonnes of CO_2 in 2008–09. This contributes detrimentally on atmospheric pollution and greenhouse gas emissions. Stubble burning is currently practiced at low levels in the Eastern Gangetic Plains, but is likely to increase as mechanical harvesting and systems intensification increase. Zero till crop establishment methods, including the Happy Seeder, are an option to allow a subsequent crop to be sown into standing rice stubble. The adoption of zero till crop establishment methods could reduce future CO_2 emissions significantly by eliminating the need for stubble burning in the Eastern Gangetic Plains.

Sapkota et al. (2019) have estimated the potential emissions reductions associated with a range of agricultural practices for different parts of India. Their analysis shows that it is possible to reduce emissions without compromising food and nutrition security, and indeed up to 80% of the mitigation potential could be achieved using only cost-saving measures. Three mitigation options that fit with CASI approaches tested in the SRFSI project could provide over 50% of the technical abatement potential: efficient use of fertiliser, zero tillage and rice water management (Sapkota et al. 2019).

The tensions between managing groundwater, emissions and food production should rely on new technologies like the Happy Seeder, as well as policy incentives associated with energy that result in full pricing of electricity. There are lessons for the Eastern Gangetic Plains, where water resources are not constrained, and crop residues are more highly valued for livestock production (Balwinder-Singh et al. 2019).

7.3.4 Climate smart business opportunities

In addition to resource conservation and improved profitability at the household level, CASI systems have resulted in business opportunities in rural communities, including for individual service providers and farmers groups, including those with solely female members, because a range of services are required for these farming systems, such as machinery provision and associated inputs like rice seedling mats.

Service providers are a critical part of the wider conservation agriculture system in a region where farms are small and fragmented, access to finance is low, and the opportunity for individual farmers to own machines and tractors is limited. Service providers fill the gap by taking on the mechanisation services as a business, and selling their services for crop establishment, harvest and post-harvest processes to farmers. Conservation agriculture mechanisation adds an additional income stream in a portfolio of services. Timely and quality service provision is a key enabler in successful conservation agriculture systems.

In West Bengal, India, farmers club/ producer organisations are acting as a linking mechanism between farmers and markets, government programs, financial institutions, research, NGOs and input suppliers research, providing training and associated conservation agriculture services. The benefit of the farmers club and famers producer organisations model is that they are embedded and supported by government policy initiatives. The introduction of conservation agriculture techniques has initiated additional income revenue streams for existing groups. Some also act as machinery distributers and centres for repairs and maintenance. Where the mechanical rice transplanter is becoming popular due to lower labour requirements for crop establishment, this technique requires rice seedlings to be grown in specific mats that are then fed into the machine; production of these mats has added another income stream for farmers' groups, particularly women.

7.3.5 Conclusion

Based on work within the SRFSI project across the Eastern Gangetic Plains, there is scope to improve climate resilience and mitigation options for smallholder farmers. Sustainable conservation agriculture practices that reduce resource use and input-related emissions associated with crop production have been tested and are being used by some farmers. Importantly, these reductions do not need to come at the expense of productivity or profitability, creating win-win situations for farmers, rural agribusinesses and governments alike, who are all struggling to find ways to adapt to climate change and reduce future levels of emissions.

These farm-level production systems operate within a wider policy context, and the interactions between policy decisions for management of different resources are demonstrated to have unintended consequences, such as the attempt to control groundwater depletion in north-west India causing an increase in fires and associated air pollution. Although the situation is different in the Eastern Gangetic Plains, such interactions must be considered and pre-empted, for example in interactions between electricity availability and groundwater use and the impact on emissions. Similarly, if mechanical harvesting becomes more widespread (as is likely with an increasingly mechanised system), residue burning may also become problematic, since mechanised harvesting changes the physical characteristics of the residue, making it harder to manage physically.

7.4 Constraints to sustainable intensification in the Eastern Gangetic Plains

Alongside distilling the lessons from scaling, work has been undertaken to understand different constraints to the implementation of conservation agriculture systems. Technical constraints to CASI implementation at scale often include those associated with soil health; 'new' weeds, pests and diseases; water management; and agronomic management (Reeves et al. 2018). Several projects were implemented to explore these constraints.

7.4.1 Soil constraints

An external review of SRFSI (Reeves et al. 2018) identified soil health as an area of particular concern in the Eastern Gangetic Plains with soil pH and associated toxicities, trace element deficiencies (zinc, copper, boron), low organic carbon levels, and soil structural problems identified as key issues. The University of Queensland worked with local partners to determine the extent of these problems (Menzies et al., 2020).

Acidification

The soils of the Eastern Gangetic Plains are poorly pH buffered, and hence at risk of acidification through product removal (crop harvest) and nitrogen fertiliser use. Acid soils threaten agricultural productivity by causing problems with nutrient availability and nodulation of legume crops, and as there are no specific symptoms, the issue can go unnoticed until the problem becomes critical. Agricultural yields within the Eastern Gangetic Plains have considerably increased in recent years, and intensification of the system (better agronomy, better cultivars, additional crops/year, increased fertiliser application) further accelerates the rate of acidification.

There is very little published data on soil acidification in the Eastern Gangetic Plains region, but in India, 16 megahectares of soil degradation is attributed to acidification, while researchers have reported soil acidification in West Bengal, Bangladesh, and the Terai of Nepal. The SRFSI project found that 15 to 20% of sites in the Coochbehar, Rangpur and Sunsari areas are acidic and require treatment, while another 30 to 45% of sites should be monitored for pH. In the Madhubani district, at least 4 nodes (87%) required lime application as a matter of urgency. The Eastern Gangetic Plains is an area of existing high productivity, current relatively heavy nitrogen fertiliser use, and an expectation of increasing usage. However, nitrogen fertiliser use is relatively inefficient and any nitrate leaching increases the extent of acidification. The overall generation of acidity varies depending on the fertiliser source. In India, ammonia-based nitrogen fertilisers (urea and diammonium phosphate) predominate in use, which results in net acid generation. Historically, calcium ammonium nitrate was widely used, which is less likely to lead to acidification but is considerably more expensive per unit of nitrogen than urea.

The predicted time for soil pH to drop to 4.5 (a critical level) is estimated at less than 10 years for the majority of sites. These projections are predicated on highly conservative estimates (relatively low yield 2.5 t/ha, and moderate nitrogen input, 100 kg/ha). Even a moderate increase in productivity (3.5 t/ha yield, 160 kg/ha nitrogen fertiliser) substantially increases the rate of acid input (13 kilomoles per hectare per year) and markedly reduces the time until soil acidity problems are likely to emerge. Irrigation with alkaline groundwater has the potential to neutralise as much as half of the acidity generated in the conservative system modelled. Thus, the time taken to reach a point at which soil acidity limits productivity may be pessimistic. Use of groundwater irrigation was not factored into the time estimates because it varies widely, while the acidification processes (product removal and nitrogen fertiliser use) are generally applicable.

While the estimates of acid input and rate of acidification are crude, they are undoubtedly sufficient to confirm that soil degradation through acidification is a considerable risk to agricultural productivity. There is an urgent need to understand the risk of acidification more accurately. An obvious aspect to addressing the acidification problem will be to ensure that as nitrogen fertiliser use increases, nitrogen use efficiency does not drop. New fertiliser technologies currently being evaluated may present opportunities to better manage nitrogen in the Eastern Gangetic Plains cropping systems.

It is also important to note that more efficient use of nitrogen fertiliser will have a positive greenhouse gas impact, and that in the long term this may be more important for climate than the carbon dynamics in the system. Any studies undertaken should consider the greenhouse gas impacts of the remediation approach. For example, simply liming to overcome acidification developed through poor nitrogen fertiliser management would result in a very poor greenhouse gas outcome.

Zinc deficiencies

Zinc deficiency in soils is known to be widespread in the Eastern Gangetic Plains, but zinc fertiliser is not commonly used. While zinc is generally present, in many soils it is found at levels that are inadequate for plant growth, with modest symptoms of zinc deficiency in rice being comparatively widespread, being most pronounced in Rangpur (Bangladesh) and India. In this study, the addition of zinc and boron fertilisers generally increased yields by around 0.5 to 1.0 t/ha, although this was not observed at all sites. Therefore, there is a need for agricultural extension projects to ensure that adequate zinc fertilisers are effectively applied to crops in order to maximise productivity.

In Nepal, the work was extended to citrus at the request of the Nepal Agricultural Research Council. Analysis of 93 leaf tissue samples from across Nepal confirmed that growth (yield) is likely greatly reduced due to nutritional constraints. Preliminary data shows that substantial increases in yield can be obtained from the addition of inorganic fertilisers. Of particular importance were zinc and nitrogen, with 98% of the samples having zinc concentrations lower than that considered to be marginal (81% below the value considered to be deficient), while 67% had nitrogen concentrations lower than that considered to be marginal (57% below the value considered to be deficient). There is a clear need to determine the nutritional requirements of crops more accurately across Nepal, especially for zinc and nitrogen. Of importance is the impact that improved nutrition has on yield and profitability. Preliminary data from project trials indicate that improving nutrition can result in marked increases in yield.

Evaluating the soil structural benefits of conservation agriculture

Conservation agriculture practices such as zero tillage are generally reported to increase soil organic matter contents, especially in surface soil layers. An increase in water stable aggregates suggests an improvement in aggregation and therefore soil structural stability in soils under zero tillage. As implemented in the Eastern Gangetic Plains however, the effect of retaining stubble and reducing tillage in the rabi season (wheat) crop, are dissipated to some extent in the kharif season (rice) crop as the benefits of improved aggregation were largely offset by traffic from equipment during the rice season which negatively affected infiltration rates.

Limited overall changes in soil structure are being reported as a result of the conservation tillage practices implemented in the SRFSI project. Nevertheless, even modest increases in soil organic carbon can result in improved soil physical characteristics, and this is an anticipated benefit of the adoption of conservation agriculture. While there are multiple reasons why increasing soil organic matter may be considered beneficial, the effects of organic matter which most directly impact on crop production are its effects on soil structure.

7.4.2 Weed management

Conservation agriculture is currently practised in over 5 million hectares in the Indo-Gangetic Plains. The greatest challenge to CASI adoption is weed control, which covers changing weed dynamics and crop-weed competition. While the agronomic implications of changes in weed management have received some attention, socioeconomic issues, farmer decision making practices and the impact on gender relations, have been less explored. Project WAC/2018/221 (Gartaula and Suri 2020) addressed this gap in the evidence base, focusing also on the gendered dimensions of weed management in the context of CASI systems in the Eastern Gangetic Plains.

CASI practices enhance biodiversity and biological processes inside and outside the soil, contributing to the maintenance of soil quality, water use efficiency, and sustaining crop production. It is a proven technology for climate variability resilience, due to the higher soil infiltration that minimises the impacts of flooding and erosion. CASI practices change weed management protocols due to a lesser number of tillages required than are traditionally used to create a clean seedbed. Herbicide usage is an integral component of CASI and is used to control weed emergence. In developing countries, especially those that are facing labour shortages in rural areas, use of herbicides has been found to facilitate agriculture intensification by making it economically viable for smallholder farmers.

This research used semi-structured interviews to discover farmer views and experiences of CASI practice in the Eastern Gangetic Plains. Due to the importance of herbicides for successful conservation agriculture uptake, opinions of its usage were sought. Often, where farmers expressed negative perceptions of herbicides or admitted very little experience of them, disadoption or a lack of further progression to zero tillage systems occurred. Of farmers who were herbicide users, there were nearly unanimous positive responses to its implementation, especially in that it saved time and cost, and reduced farm drudgery. Positive comparison made between hiring multiple labour against purchasing herbicides was also common.

While herbicide use in the region is not a new phenomenon, there remains a low level of awareness on both safe handling and storage techniques, and their associated human health aspects. Environmental literacy, comprising safe use of herbicides, health hazards, concerns over air and water pollution, and long-term ecological problems and trade-offs, can be packaged through zero tillage technology promotion. This would assist in risk minimisation as well as reducing negative impacts on the environment.

It was also found that spraying of herbicides is becoming the male member's responsibility due to spray tank design and weight. Thus, zero tillage technology usage has had some gender implications. This is more apparent in areas where there is higher tendency of male labour out-migration and that may consequently increase the wage rate of male labour with such 'male-friendly' technologies.

Zero tillage was found overall to provide time-saving benefits for both male and female farmers, especially for women due to the reduced weeding requirements, with no shifting of the burden of weeding from men to women. With some diversities across the Eastern Gangetic Plains owing to different sets of drivers and benefits, generalised time savings during crop production have been found, pointing positively to plans for subsequent scaling out in the region. However, knowledge of weeds that grow in zero tillage fields is limited, with women farmers able to name fewer weeds than men. Based on further in-depth research on gendered farmer knowledge on herbicide usage, an agronomic literacy program on the effective, efficient, and economic management of weeds would help promote zero tillage technology. Such agronomic literacy programs can be tailored through existing extension service mechanisms prevalent in the region.

Understanding the weed management problems and evaluating practices used by men and women farmers to manage weeds in these systems successfully will be important components of efforts to develop efficient weed management packages and thereby facilitate the further sustainable intensification of smallholder farms in the Eastern Gangetic Plains. The promotion of CASI must incorporate the understanding that the shift from conventional agriculture to conservation agriculture systems involves a change in farmers' cultural practices and a paradigm shift around management of crops and resources such as soil, water, nutrients, weeds, and farm machinery. Therefore, there is a need to establish a systems perspective; a holistic perspective including knowledge transfer, especially around weed identification, better management practices, and safe handling of herbicide use. Scaling up of conservation agriculture technologies may be more about farmer perceptions and mindset than about the technology itself.

CASI promotes equality of opportunities and outcomes and may help farmers take up additional economic activities and expanding livelihood portfolios due to the time savings generated by herbicide use. This is of particular significance for women, who are finding more time available for tasks of their choosing, instead of the drudgery associated with traditional weeding practices.

7.5 Locally relevant knowledge sharing mechanisms

7.5.1 Syngenta Farmer Hubs in Bangladesh

Across the Eastern Gangetic Plains, there is a predominance of small and localised private businesses that provide agricultural inputs, machinery services, and sometimes aggregate and market produce. In this context, an understanding of which methods are best suited for the scaling of certain agricultural technologies to large numbers of small-scale farmers is critical.

Finding ways to foster linkages between research providers, extension officers, these types of private businesses and farmers to enable scale-out of improved agricultural technologies is an ongoing challenge. Farmers' Hubs (see www.syngentafoundation.org/agriservices/whatwedo/farmershub) were developed by the Syngenta Foundation for Sustainable Agriculture and are designed to provide multiple services such as the purchase of inputs including seed and seedlings, selling farm produce, and access to machinery as a commercial business. Six sample hubs out of a total of 286 hubs in Bangladesh (as of December 2020) were selected from Rangpur and Rajshahi divisions, including one run by a small ethnic community group. We conducted a quantitative survey of farmers who engaged with the selected hubs (participants), and non-participant farmers who live in nearby villages. A total of 323 samples were collected. In addition to the quantitative survey, participant observation, key informant interviews, and expert consultation were performed to capture the diverse perspectives.

The most common service provided by the hubs was the selling of vegetable seedlings. This involved the development and use of coco-peat media in seedling trays and the use of crop types and varieties that had been trialled by the Syngenta Foundation for Sustainable Agriculture research team and were optimised for local conditions. This seedling technology and practice information provides farmers with a much lower mortality rate for seedlings, earlier harvest for some crops and can lead to a price advantage at the time of sale. However, not all farmers purchase seedlings through the hub alone as the price of these is high relative to other sources or the use of farmer-saved seeds, as the seedlings are grown under controlled environment and production cost is relatively higher in the hubs.

Hub owners and network managers act as aggregators of produce from many farmers, and this enables access to distant markets at a better price – 42% of respondents used this service. According to Syngenta Foundation for Sustainable Agriculture Bangladesh, direct buying and selling of farm output was one of the major sources of income by the hubs (about 19% of the profit received in the first 6 months of 2020). However, not all farmers are getting benefit from this service. Hub participants also accessed some machinery services from the hub, such as power sprayers, mechanical weeders, and seedling transplanters. For hub participants, some information across all information types was provided by the hub, but the choice of which variety to use, the crop type choice, pesticide use advice and fertiliser use advice were the most identified by hub participants. In the non-participant group, sellers, traders and extension agents provided information about pesticides and fertiliser use.

All survey respondents were able to slightly increase their productivity over the short time scale we assessed (2018 to 2021). A greater proportion of hub participants said their productivity had greatly increased, whereas non-participants said their productivity had moderately increased. For hub participants, this change was attributed to a shift from the use of seeds to the use of high-quality seedlings and the fact that they had adopted a new crop or variety. Given the relatively young age of the farmers who are participants of the hub, this is a big change to their farming systems and demonstrates one of the harder-to-measure aspects of participation in hubs (or other collective groups), that is the de-risking of practice change through support and knowledge.

The hubs have not been successful in engaging women entrepreneurs to lead activities and we had few women respondents included in our quantitative survey, which limits the conclusions we can draw. However, during the scoping trips and field visits it was observed that female labour was involved in seedlings preparation and other hub-related activities. The hubs have been successful at attracting young entrepreneurs and developing their capacity to lead a farming business.

Syngenta Foundation for Sustainable Agriculture introduced a digital tool called e-FarmersHub, which helps hub owners keep track of daily transactions, get automated business analysis, inventory, customer, and marketplace information, while enabling the Syngenta Foundation for Sustainable Agriculture to monitor progress in real time. Most respondents do not currently use digital tools in farming at all and were unsure about how they could use them to their advantage in the future to improve their agricultural practices. However, many respondents would like to use smart phones and computers to access digital tools and apps relevant to agriculture more in the future.

The hubs already play a broader role in the rural communities in which they are based, and several social service roles the hubs could play in the future were identified. Suggestions included a club or training centre for farmers, education and library facilities for children and farmers, and health facilities. A financial support role was mentioned but this was not limited to loans to support farm businesses, but also resources and funds to help poor members of the community.

This study contributes to an understanding of how the public and private systems and institutions interact in Bangladesh to assist in the scale-out of agricultural technology.

While the differences observed between participants and non-participants of the hubs were subtle, there was some evidence that the hubs are supporting younger farmers to trial, adopt and see the benefits of more challenging farming practices. There are flow-on benefits to farming communities through greater capacity and confidence of farmers that is hard to value. The trialling and optimising of practices in the local context before they are scaled-out to farmers is a critical step in the adoption process that if missed, can lead to disadoption of practices.

The hubs should have a greater emphasis on de-risking the adoption process for farmers for a diversity of services they provide (that is, not just seedlings), and there may be some benefits to expanding this to machinery services. To assist in this process there should be more connection and collaboration between the hubs and The Bangladesh Department of Agricultural Extension. Currently there are informal interactions but there may be benefits to making this relationship more formal (through institutional linkages). Further research on vegetable value chain development in the north-west of Bangladesh may provide insights into how higher value agrifood systems can be implemented from aggregated products. The intersection between the use of digital tools to facilitate product aggregation and sale at a price high enough to provide equitable outcomes for all stakeholders is one area that requires further research. The full report is by Macfadyen et al. (2021).

7.5.2 Supporting agriculture in the process of federalisation in Nepal

Nepal is in a transition phase as the full implementation of the new federal system is still underway. This period of change means translating the newly enshrined constitutional rights to food and nutrition security and food sovereignty into effectively working systems at the local government levels. The changed federal structure gives more power to local governments at the municipal (rural and urban) level, adds a provincial level of government for facilitation and support, and changes the role of the federal government to policy, governance, knowledge and oversight issues. This restructuring brings enormous opportunities for agriculture sector services to be prioritised and managed at the local level, bringing the government closer to the people.

But there are challenges associated too, in changing roles, responsibilities and funding mechanisms. For agriculture, the new system means that agricultural services are primarily the responsibility of the provincial and local governments, while research remains at the federal level. Stakeholders at all levels recognise the need for coordination mechanisms to ensure that the new system operates effectively. In this context, ACIAR SDIP is working at several levels to support the transition to federalisation to ensure effective agricultural services.

In the foresight component, the Centre for Green Economic Development led work on understanding the wider food system in the Nepal Terai (Subedi et al. 2020), and exploring the current situation for agriculture in the new system. They found a multitude of policies and plans that related to agricultural development at all levels, but also challenges in both their coordination and implementation. Discussions with local municipal and provincial staff and community members revealed a lack of staff to fill assigned positions in various government offices, a lack of subject matter specialists, and low budgetary spending despite allocations. These initial constraints could be seen as areas of potential risk that must be managed to allow the implementation to unfold effectively.

A high-level policy dialogue was conducted in Kathmandu that attracted over 40 participants, including policymakers from federal and provincial government levels, and other relevant organisations. The objective was to present the evidence and ideas from the initial work, and to get feedback on priority areas for research and support within the new system. Key themes that emerged included the lack of mechanisms that exist for coordination and collaboration, both vertical and horizontal. Policy dialogue was recommended to include local governments to demonstrate promising techniques and ensure informed decision-making. Another important area was the need to link the new Agricultural Knowledge Centres with research and other knowledge sources. The importance of building human resource capacity across all parts of the system was highlighted.

In the next phase of foresight work in Nepal, the team from the Centre for Green Economic Development together with the Department of Agriculture and the International Water Management Institute will use foresight approaches as a dialogue tool to identify preferred pathways towards a resilient food system, through identifying synergies between the different levels of government who are responsible for delivery of agricultural services. This project will incorporate recommendations from the peer learning workshop and science policy dialogue to align with identified priorities.

The activities within the ACIAR SDIP program have highlighted the potential for CASI practices to improve the livelihoods of those in rural areas of the Nepal Terai. This has led to the development of substantial recommendations to create enabling environments that facilitate the uptake of CASI in farming communities. Yet there remains a gap in how to 'put into action' such recommendations. CIMMYT is leading a project that focuses on 'Building Provincial Capacity for Sustainable Agricultural Mechanisation in Nepal' to address this gap through the production of participatory roadmaps. Roadmapping is a flexible planning technique to support strategic planning and programming. This process is being developed and applied in Province 1 and 2 in Nepal, where the SRFSI project has been working since 2012. It is exploring the pathways for increased CASI mechanisation through a series of activities that aim to improve linkages and capacity to create and maintain enabling environments. This project responds directly to the need within the new federal structure for cooperative mechanisms at the provincial level.

In several projects and activities, we have explored the challenges and opportunities for Nepal's food systems in the context of federalisation. The existing work goes some way to defining the context, and understanding priorities at different levels of government, to reach a consensus on preferred pathways towards sustainable food systems. The work on mechanisation offers a linking mechanism for one part of the agricultural system at the provincial level. As recommended by policymakers, what is missing is testing and supporting mechanisms for coordination and collaboration for local government to define and implement sustainable food systems and inclusive methods of water management, in the context of their increased power and budgetary availability.

8 Lessons for regional program approaches

The ACIAR SDIP program has focused on understanding the context and enabling conditions for the development and scaling of sustainable and resilient food systems in the Eastern Gangetic Plains. Experience from the program approach highlights lessons for important elements to include in research-for-development activities that can help to address complex challenges.

8.1 Capitalising on working across locations

The SDIP had a regional focus at the portfolio level, and ACIAR chose to focus on the Eastern Gangetic Plains, at the request of partner governments, as a place with high levels of poverty and serious constraints to agricultural production, and yet with major potential to become a major contributor to regional food security. The Eastern Gangetic Plains, although a contiguous area, has very different political, policy and institutional settings, and covers a range of agroecological zones. Most projects worked across locations, with the benefits being cross-site learning, exchange of ideas among different team members, ability to contrast and compare different results to learn lessons for the future development of the Eastern Gangetic Plains.

In Phase 1 (the SRFSI project), the research and development activities under the project were conducted in 40 nodes in 8 districts across the Eastern Gangetic Plains in Bangladesh, India and Nepal. These locations were chosen specifically to test techniques in a range of agroecological settings, as well as to enable cross-border comparison of results (for example, Nepal and Bihar; Bangladesh and West Bengal), and to explore the effects of institutional and policy settings. These locations became the basis for subsequent work, although additional sites were also included depending on the project, and particularly in Nepal.

8.2 Working across scales

For a range of issues, projects have worked at multiple scales, from individual to household, community and regional levels. Macro-level data let us understand the broad context for diverse elements such as gender, foresight and groundwater development. Connecting this macro-level data with micro-level data provided a more nuanced understanding of the factors influencing food systems, and let us look for levers of change where they might be most effective. There are multiple examples of linking macro and micro scales, both in individual projects and within key themes.

When researching the role of women in agriculture in the Eastern Gangetic Plains, the analysis of national-level secondary data showed feminisation of agriculture in Nepal and Bangladesh, and 4 reasons for defeminisation in India. A primary survey was carried out based on exploratory qualitative field work in selected locations to provide location-specific explanations for women's changing role in agriculture. The field insights reveal information not available in labour survey databases, including the influence of changing cropping patterns, transformation of land uses, and increasing mechanisation. The primary survey complemented explanations provided by the macro analysis in several ways. While the macro analysis suggested an increase in the share of male cultivators which can be interpreted as return of men to agriculture, the primary survey revealed that men are in fact moving back to agriculture in the form of seasonal work during the times of peak labour demand due to lower availability of jobs in urban areas. This in turn is rendering the women jobless or leaving them with less than full employment. These complex processes need to be followed up by detailed research based on systematic primary surveys representative of sub-regions to inform policymakers so that enabling interventions can promote gender equity based on women's meaningful engagement in agriculture in the region, rather than a one size fits all approach.

The foresight work first focused on understanding higher-level drivers of food systems in the Eastern Gangetic Plains. Subsequently, a package of work was developed that focused on local-level (Bangladesh, West Bengal, and Nepal) and national (India) activities to inform and improve the future of food systems in the Eastern Gangetic Plains region and to strengthen local capacities for scenario-based foresight exercises through training, mentoring and supporting a learning-by-doing approach. Ideas for the local and regional foresight activities emerged from the discussions and evidence generated in a training workshop held in February 2019. The aim of this work was to connect the big picture context with work at the local/regional level where change can happen.

Several projects contributed a better understanding of options for sustainable groundwater development. Multiple studies within ACIAR SDIP confirm that groundwater in the Eastern Gangetic Plains is an underutilised resource in many locations, and so a better understanding of availability and the implications of its management alongside energy and food policies is critical to maintain sustainability. Work has been undertaken to explore the wider impacts of changes to farm-level management of water in response to conservation agriculture and changed energy policies. Understanding these changes demonstrates the importance of understanding the integrated nature of water, energy and food decisions; and points to areas that policymakers can prioritise which can achieve sustainable outcomes.

8.3 Multi-stakeholder engagement

The SDIP aim was building capacity for regional integration, so at all levels there was a focus on engaging with multiple stakeholders. Capacity building has been a key area of focus in both phases of ACIAR SDIP, and working on building capacity in several different areas and using a range of methods to improve the enabling environment for scaling sustainable food systems in the Eastern Gangetic Plains. In focusing on multi-stakeholder engagement as a critical element of the program it meant that capacity building was important to ensure people were on the same page and able to contribute to their best potential. There are a range of examples that show how different projects have engaged with multiple stakeholders throughout the program to bring together different actors in the food system.

In the SRFSI project, institutional arrangements to support the adoption of CASI were predicated on the idea of working with multi-stakeholder groups or innovation platforms. Innovation platforms are groups of stakeholders that interact within an agricultural system to solve problems at the local level. These groups have actively included the local private sector, which 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 levellers and mechanical rice transplanters, reapers); agroprocessing; and seed multiplication and certification services. 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. Innovation platforms are also a way to leverage public extension systems through coordinating local stakeholders and providing an interface between extension officers and smallholders. Local innovation platforms 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. Importantly, the experiences in working with innovation platforms across 3 countries have 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.

The VMP project is a pilot project testing feasible commercialisation models for scale out of the conservation agriculture-based planter developed in a previous ACIAR project. It specifically collaborates with Hoque Corporation (a manufacturer), the Conservation Agriculture Service Providers Association (CASPA), and the National Bank Ltd. In this project, Hoque Corporation leads the VMP manufacturing, and piloting of VMP commercialisation models. It works with CASPA to identify new and prospective local service providers of the VMP. The National Bank Ltd works together with all partners to help new local service providers to secure a loan for purchasing of the VMP alone or with a 2WT. In bringing together the partners necessary for production, access to credit and use of this machine, the intention is to smooth the process and make it easier for more farmers to access the machine.

In the foresight component, multidisciplinary teams were brought together to understand the drivers and trends outside the farm which influence the food system. These participants represented a range of sectors, expertise and career stage related to the wider food system. The advantage of bringing in people from various disciplines is that it helps to understand the broader context within which farm production takes place.

8.4 Convergence with existing programs

Convergence (that is, aligning project activities with existing government and development programs) offers scope for scaling that is not always possible in a research project. Key elements of the approach to achieving convergence are highlighted in Figure 9. These include:

- Policymakers in South Asia care about things that are close to their constituents, and farmers are an important part of it. Addressing farmer distress can win elections. Working with partners at multiple levels from farmers to policymakers builds ownership, and they are interconnected and influence each other.
- Local trials provide evidence that a particular innovation in technology and institutions are grounded in reality.
- It is important that we create space for members of the agricultural innovation system to interact and engage with each other, building on successful models in different locations.
- Partnerships with established international partners and national partners adds value as it has a bigger influence and adds credibility to research results.

8.5 Adaptations and innovations used to operate flexibly during COVID-19

The COVID-19 situation in 2020–21 created very difficult conditions for project teams. We undertook COVID-19 response planning as soon as disruptions were clear in March 2020. The major impacts were on primary surveys and physical meetings. Many of these approaches will be used in the future to maintain communications, adaptive planning and delivery where regional travel may be difficult for the foreseeable future.

As a program, we used a range of approaches to operate throughout this period, including:

- Regular personal contact with project leaders to understand the impact of COVID-19 on project activities.
- Extending individual project end dates as much as we could to allow projects to re-organise work plans as needed, including budgets.
- Working with individual projects to re-prioritise deliverables, which in some cases meant changing target outputs. For example, project teams delayed surveys and/or adapted data collection methods; a large field survey planned by the institutions project switched to using available secondary data and

Figure 9 Important considerations on the pathway to impact

connected with the SRFSI project to use their primary data to analyse in an alternative way.

- Constant evaluation and adapting of plans throughout 2020–21 as South Asia faced several waves of COVID-19; and checking in regularly to make sure our colleagues were okay.
- Reporting to DFAT on disruptions and plans to work around them.
- Reducing workload related to the program as much as possible during peak COVID-19 events. For example, we requested an extended end date for the program from DFAT, delaying the end of the program by 3 months to shift key reporting and meeting dates past the second COVID-19 wave in India and Nepal.
- Shifting meetings to online events. Even projects working at provincial/district levels were able to maintain scheduled meetings, although the effectiveness of these was not necessarily as good as it would have been in person.
- Starting a monthly webinar series to communicate individual project results.
- When commissioning additional research activities during COVID-19, we constrained these to desktop studies and recognised that in-person activities may not be possible.

8.6 The value of a program approach

The benefits of a program approach experienced during the ACIAR SDIP program are multiple. These benefits rely on dedicated staff who have time and resources to play a supporting, convening and integrating role to ensure that program-level benefits are realised. Benefits include:

- An efficient research process utilising established research infrastructure, networks, research sites, and others.
- An ability to look at an issue from several different angles and at different scales.
- Exploring cross learnings and links across diverse pieces of work.
- Synthesising across different – and emerging – themes.
- The ability to be flexible, for example, in undertaking discrete pieces of work as knowledge gaps emerge. Importantly, these are often able to be done with local partners who have excellent local and regional knowledge and connections.
- Maintaining partnership networks as a solid platform for project work.
- Adds a wider narrative, and helps to move ACIAR work along the research-to-development continuum.
- Creates a platform for debate, sharing and convergence.
- Brings together research and community levels, which gives relevance on the ground.

9 Impacts

The program has demonstrated impact across science, capacity and community sectors during the 9 years of operation, and these impacts will continue to be felt in the coming years.

9.1 Scientific impacts – now and in 5 years

The use of conservation agriculture practices has been rigorously tested across 8 districts of the Eastern Gangetic Plains, and more than 3,000 trials have contributed to identifying the impact of changing practices for a range of indicators, including biophysical, socioeconomic and environmental. Results have been published in 20 journal papers and presented at a range of conferences, making a significant contribution to the knowledge base for conservation agriculture in South Asia, specifically focused on the often-neglected Eastern Gangetic Plains.

In addition to the farm-level testing of conservation agriculture, work has also been undertaken to scale these approaches, and new knowledge based on these scaling approaches has been identified. In Bangladesh, models of cost-sharing between public–private partners have been identified that lead to sustainable scaling.

New approaches to research and new knowledge which promotes a more nuanced macro and micro understanding of women's roles in agriculture in the Eastern Gangetic Plains, and the impacts of systems change, have been identified. For example, a new methodology was developed to allow comparison of secondary datasets between Nepal, India and Bangladesh, specifically related to women's engagement in the workforce. A study which explored the impact of weed management under CASI on women's labour found no additional burden; this addresses the currently limited understanding of how gender norms in the Eastern Gangetic Plains affect knowledge of and responsibilities for agricultural activities, particularly in relation to the uptake of CASI practices.

There has been a substantive body of scientific knowledge of novel methods to assess institutional effectiveness in the Eastern Gangetic Plains. Primary data collected from expert communities and the novel application of the Delphi and best-worst scaling techniques to generate the institutional mapping are particularly valuable. This represents a substantive contribution to the New Institutional Economics literature and development analysis.

The program has contributed new knowledge to sustainable groundwater development in the Eastern Gangetic Plains, using a food-energy-water nexus lens. Individual projects have looked at patterns of availability and access to groundwater, local-level water management solutions (such as CASI, aquifer storage and recovery), and the impacts of commonly used policies aiming to influence groundwater development and sustainability. Results indicate the links are not always as expected. For example, increased access to electricity has not resulted in a strong change in groundwater use or productivity in West Bengal; and water savings at the farm scale do not always result in reduced groundwater use overall. In the Eastern Gangetic Plains, impacts of climate change will result in delayed monsoons and increased incidence of flooding, which makes summer crops more vulnerable to water stress (both too much and too little). Groundwater resources, which in many places are annually recharged (as at least 4 ACIAR SDIP studies have confirmed), are more resilient to climate change and offer assured irrigation in the dry winter months.

The weeds and soil projects identified challenges and opportunities for further research to address them.

Appendix 3 contains a list of project publications current at the time of the program ceasing; many additional papers are under review. In 5 years' time, the scientific knowledge generated in this program will have continued to be published. Application of this knowledge can improve planning processes in the Eastern Gangetic Plains. In particular, the scientific basis for promotion of CASI and more holistic understanding of groundwater can promote a more sustainable development pathway for the Eastern Gangetic Plains.

9.2 Capacity impacts – now and in 5 years

Capacity development across a range of spheres has been a focus of the program from the start. In total, the program has supported 72,292 people (27% female) to undertake professional development and/or technical training opportunities, including short courses, study modules, and high-level study tours. There were 1,934 people (53% female) who participated in key knowledge/dialogue/policy forums. There were 26 people (5 female) supported to undertake master and PhD programs.

Novel extension methods have been used to promote CASI to different stakeholders. Over 8,000 participants joined the first ever Massive Open Online Course covering CASI, delivered by Bihar Agricultural University in partnership with CIMMYT. This course provided a comprehensive overview of CASI to an audience ranging from farmers to extension officers and policymakers.

The SRFSI scaling strategy was focused on building capacity to improve the enabling environment for large-scale uptake of CASI innovations. This consisted of a tiered approach to training: experts (L1) who provided training for trainers (L2), who then delivered training to farmers and communities (L3). The focus of training was on technical elements of CASI, but also associated supporting skills in topics like business and finance. The number of people trained in this activity constitutes a significant proportion of the training number provided here, and has resulted in a cadre of people trained in CASI techniques who can support the implementation of CASI at the local level. Building on this, the Government of West Bengal is establishing a Centre of Excellence for Conservation Agriculture at Uttar Banga Krishi Viswavidyalaya (North Bengal Agricultural University), with the aim of training 2,500 people per year in CASI approaches. This will have long-term implications for supporting conservation agriculture in the north-east region of India for many years to come.

In the foresight component, one of the aims has been to help our partners to bring together the 'big picture' related to sustainable food systems, through application of foresight processes in the

Eastern Gangetic Plains. This work has included engaging key stakeholders in informed dialogue on the drivers and trends for regional food, water and energy security through enhanced foresight and scenario processes. More than 200 researchers, planners, policymakers, entrepreneurs and civil society members from Bangladesh, India and Nepal came together over a series of workshops for planning, learning, and information sharing. These workshops helped build and strengthen a core group that is interested in undertaking foresight for food exercises in the region.

Regular opportunities have been provided for cross-country learning and knowledge sharing on a range of topics. Together, these approaches have built capacity to support and apply technical (for example, CASI, groundwater management, institutional analysis) and systems approaches in the Eastern Gangetic Plains that can help contribute to better regional cooperation.

In 5 years, with the Centre of Excellence for Conservation Agriculture opened in 2021, an additional 12,500 people will be trained in CASI approaches, focusing on ensuring the training sessions are gender-inclusive and youth-inclusive. This will build a cohort of people who can support CASI scaling in the region.

9.3 Community impacts – now and in 5 years

The program has focused at the community level in terms of understanding the impacts of systems change associated with CASI approaches. CASI farming practices increase productivity and farm incomes, and have emission reduction benefits. In total, around 120,000 farmers (25% female)[2] are now using CASI techniques. As well as direct benefits for farming households, CASI also provides business opportunities in local communities.

In 5 years, if 5% of the rice–rice, rice–wheat, rice–maize and rice–lentil systems adopted CASI approaches, this would mean covering 0.7 million hectares, and involving approximately 1.2 million farmers. If 20% of these farming systems adopt CASI approaches, this means covering 2.9 million hectares and involving 4.8 million farmers. Specific economic, social and environmental impacts are detailed below. Adoption at scale would reflect the impact of both phases of the program.

9.3.1 Economic impacts

At the farm level, rice–wheat, rice–maize and rice–lentil systems using CASI practices resulted in significantly higher gross margins of around 20%, compared to conventional tillage, with the gross margin of the partial CASI practice also higher than that of conventional tillage in all systems (but not significantly so in the rice–lentil system). Average gross margins for CASI and conventional tillage in cropping systems include rice–wheat (AUD$1,097 compared to AUD$869), rice–maize (AUD$1,965 compared to AUD$1,672) and rice–lentil (AUD$1,605 compared to AUD$1,344). These gross margin data directly reflected the lower costs of production under CASI than under conventional tillage practices. The cumulative impacts of this adoption over the life of SDIP up to mid-2021 includes an estimated additional AUD100 million in farm household income, and AUD60 million in reduced production costs. Additional modelling of the risk associated with CASI adoption showed that there is more risk associated with CASI in the early years of adoption compared to conventional tillage, given low levels of experience and higher

2 Number of farmers using CASI practices is reported by partners, who receive information from block-level Department of Agriculture staff.

costs associated with informal lending (compared to trial data) – these risks must be managed for CASI to scale sustainably.

If 5% of the appropriate farming systems adopt CASI approaches, this means an additional AUD520 million in farm household income annually. If 20% of the appropriate farming systems adopt CASI approaches, this means an additional AUD2 billion in farm household income annually. This does not take into account additional income for service providers and those supporting the mechanisation.

9.3.2 Social impacts

In CASI systems, labour is reduced by 15% to 43% depending on the techniques used and the cropping system. In all cases, reductions in labour use are significant compared to conventional production systems. These labour savings have been demonstrated to allow households, particularly women, more time to pursue alternative productive and reproductive tasks. In addition to reduced labour, drudgery associated with land preparation, transplanting and hand weeding is also reduced.

In the program operating areas, farmers generally access CASI machinery from service providers, which presents opportunities for small businesses to provide machinery services locally where there is sufficient interest in a community to create demand. These business opportunities also provide opportunities for women, for example in production of rice seedlings for mechanical transplanters; and to own machines as part of group assets. There have been 445 people or groups supported to become micro-entrepreneurs for service provision.

9.3.3 Environmental impacts

In accounting for emissions from on-farm production inputs, compared to conventional tillage, CO_2-e emissions under full CASI were significantly reduced by 14% in rice–wheat systems, by 11% in rice–maize systems, and by 10% in rice–lentil systems. Total energy use was reduced by a similar amount.

Water use varied between cropping systems and was also dependent on management. In the rice–rice, rice–wheat and rice–maize systems, significant irrigation use declines were observed (15%, 17%, and 25%, respectively) when CASI techniques were used. Greatest irrigation water savings (of 53%) were observed in the rice–wheat–jute system. Use of irrigation water under CASI compared to conventional agriculture increased in the rice–lentil system by 10%. In terms of total in-crop water use (irrigation and rainfall), total water use was significantly lower in the rice–maize (2%), rice–wheat (4%), rice–rice (8%) and rice–wheat–jute (11%) systems. All cropping systems were significantly more water productive under CASI than under conventional agriculture approaches. Based on the current adoption level of 120,000 farmers using CASI approaches, it is estimated that 60,000 tonnes of CO_2-e have been mitigated, and 63,000 megalitres of water saved within the program's lifetime.

If 5% of the appropriate farming systems adopt CASI approaches, this would mitigate an additional 155,000 tonnes of CO_2-e and reduce water use by 548 gigalitres annually. If 20% of the appropriate farming systems adopt CASI approaches, this would mitigate an additional 740,000 tonnes of CO_2-e and reduce water use by 2,192 gigalitres annually.

9.4 Communication and dissemination activities

Communications have been a major focus of the project during Phase 2. The program team has implemented a multifaceted communications strategy that includes digital (website, social media, bi-monthly e-newsletter, webinars), print (reports and briefs) and film platforms to communicate program structure and project outputs. The program website (aciarsdip.com) was launched in June 2018 and is regularly updated. Since June 2018, it has received 25,000 page views from 9,000 visitors. The website contains information about the ACIAR SDIP program and projects. It also acts as a repository for project reports and communication materials.

A series of films highlighting elements of the ACIAR SDIP program were developed and are hosted on the website and shared with partners and wider audiences through social media using ACIAR and partner accounts, and in physical meetings. Films produced include:

1. Agriculture and the food-energy-water nexus
2. Household level impacts for Sulochana Devi in Bihar
3. High Commissioner Julia Niblett meets farmer Lucky Begum in Bangladesh
4. The role of women in agriculture in the Eastern Gangetic Plains
5. SRFSI: The West Bengal Story
6. Kalpana's story
7. Markets working for farmers
8. Stories of most significant change
9. Electrifying groundwater irrigation
10. Better measurement of women's work and empowerment
11. Regional impacts of on-farm water saving
12. Farmer foresight stories.

The program has organised 13 webinars in 2020–21 to ensure continued dissemination of findings, with results from Small Research Activity projects presented by project teams. These webinars were promoted through ACIAR and other social media, open to a wider audience and received good attendance and participation from a wide range of interested parties.

Linking ACIAR SDIP with existing ACIAR projects in South Asia has been pursued in several ways. The aim was to share experience and expertise in intensification of farming systems in the Eastern Gangetic Plains region across a range of disciplines, scales and approaches to understand the synergies and trade-offs across the work already being undertaken by ACIAR. Relevant project leaders have been invited to program meetings, with a workshop focused on Diversification for Sustainable Food Systems in South Asia held in December 2018 to bring together 30 researchers representing 10 research organisations from Australia and the CGIAR, including ACIAR research program managers (Water and Climate Change, Crops, Horticulture, Livestock and Farming Systems) and regional staff; partners from the SDIP; and other researchers working in the Eastern Gangetic Plains.

Integrating across the program has been necessary given the diverse program structure, with 20 projects of varying sizes and complexity. This integration was managed by having 2 full-time staff based in the region who were dedicated to:

- program management and regional coordination
- frequent communication through newsletters and the website to share information and resources

- working with existing partners across different projects at the local and regional level
- selecting new partners who work in a collegiate way.

The foresight component is being used as one way to integrate different elements of the program. For example, Professor Sucharita Sen contributed to all foresight meetings, bringing her background in social geography and results from the study into the role of women in agriculture in the Eastern Gangetic Plains. This helped share the findings from this study across different parts of the program. Similarly, several local partners were engaged in work from farm, institutional and foresight levels, and they helped bring a ground-check to the wider thinking in terms of influences in food systems. Data sharing has occurred, for example, between the SRFSI and institutions projects, where data from on-farm research trials was re-analysed to look at different risk profiles. Responding to the key theme of climate change as a focus for SDIP, a standalone report synthesising the different pieces of work around climate change was undertaken, with elements of field- and farm-level impacts on emissions, resource use and soil dynamics considered, as well as modelled performance of conservation agriculture verses conventional agriculture systems under different climate scenarios, and the potential impacts of wider adoption of conservation agriculture-based systems across the Eastern Gangetic Plains.

Public diplomacy efforts have been made to contribute to raising Australia's public profile through ACIAR SDIP activities. High Commissioners from India and Bangladesh, and the Ambassador to Nepal have all visited project sites and joined high-level workshops and meetings. West Bengal has been a site of success for CASI activities, and as a priority state for Australia as identified in the India Economic Strategy, can offer leverage opportunities for DFAT. Water is an established strand of the Australia–India bilateral relationship, supported by a high-level formal agreement. Australia is internationally recognised for its water resources management expertise and is an established and trusted partner in the Indian water sector. With the Indian Government launching large-scale infrastructure projects in water, Australia is well-positioned to assist India to strengthen its water governance and management systems and support increased engagement by Australian companies in the Indian water sector. India has launched the National Water Mission with an aim to improve the efficiency of water use by at least by 20%, and agriculture, industry and domestic water are key areas of focus. They have identified the use of micro irrigation, promotion of water neutral and water positive technologies, and recycling of water as key measures for increasing efficiency. This offers an opportunity for DFAT in India to explore agriculture as an entry point to engage on policy development, including through water-efficient agriculture. In terms of climate, a regional understanding of how food systems are changing can help with longer-term climate smart and resilient planning and investment; and cultivating productive relationships can help position Australia as a trusted and useful partner for India's own policy objectives.

10 Conclusion and opportunities for future work

The ACIAR SDIP Phase 2 program goal has been to maximise agriculture's contribution to sustainable food systems in the Eastern Gangetic Plains, for improved food, energy and water security. The program has transitioned from identifying and promoting sustainable farming technologies based on conservation agriculture, to a focus on understanding the wider context of the food system and the various external factors which influence sustainable food production. The program has worked to promote resilient and inclusive food systems supported by robust institutional arrangements, policies and strategic regional planning, in the context of a changing food system.

The program's second phase had ambitious goals in a short timeframe, with work planned to be delivered from mid-2018 to mid-2020 and then extended twice to September 2021. The COVID-19 pandemic caused delays to several projects and meant primary data collection was not possible for 2 of the larger projects. Importantly, the pandemic also prevented planned synthesis and knowledge sharing events which were to take place at the end of the program. These have been difficult to deliver online, although webinars have served the purpose of communicating individual project outputs.

Despite the pressure of time from the start, the program has:

- delivered a wealth of information around the context for food systems in the Eastern Gangetic Plains
- identified effective institutional arrangements
- supported an improved understanding of the scaling of sustainable farming techniques
- built capacity in a range of areas from mechanisation to foresight processes
- contributed evidence to the understanding of the unique food-energy-water nexus in the Eastern Gangetic Plains
- identified broader constraints in our understanding of gender in agriculture.

Work from several individual projects demonstrates the importance of an integrated understanding of the system as a whole for sustainable, profitable and resilient food systems to be achieved.

Although the program has covered a broad span of the food system, there are some areas that have been less well studied. This includes nutrition and dietary diversity, which has been touched on but deserves more attention. It may be possible to link with different programs and organisations with a nutrition focus in the future. Farm-scale projects have focused mainly on cereals, and there is scope and demand from partners that more diversified systems be considered in new projects. Market systems have not been a major focus, apart from localised work on mechanisation; expanding this would be an important part of future projects, particularly when incorporating a diversified livelihood systems focus.

The ACIAR SDIP program has set the scene for future work in the region by producing a body of work that demonstrates the potential for change from farm to regional scales. Future work can capitalise on this work by integrating the lessons and allowing time for their implementation and further learning, to contribute to understanding the processes for transformation of food systems. Elements that need to be built on to achieve this include:

- Consolidate the lessons from different scaling approaches to draw out key elements that are needed to support food system transformation.
- Explore the capacity for implementation of policy settings, building on the work done by several projects in this program.
- Refine recommendations to optimise policies that impact the food-energy-water nexus in the Eastern Gangetic Plains, including a better understanding of water markets and how they respond to energy, water and food policy. Completing the primary survey developed by the University of South Australia can help contribute to this understanding by providing farmers' experiences and preferences for institutional arrangements.
- Address the lack of studies and key data in the Eastern Gangetic Plains that clearly establish a farm to region water balance. Time series spatial data on actual evapotranspiration is particularly lacking. Studies at a range of scales, from farm to region, are required to determine the impact of farm-scale water saving measures on regional hydrology.
- Target research on the impact of climate change on Eastern Gangetic Plains agriculture remains limited and needs to be significantly increased, especially in relation to crop heat resilience, changes to insect pest/pollinator regimes, and crop responses to elevated CO_2 concentrations. Farmers and policymakers alike need climate smart, profitable production systems that can help them deal with climate variability and maintain food and nutrition security.
- Address soil acidification, including the different forms of nitrogen supply, and the level to which groundwater irrigation can neutralise acidification.

Several of these research themes will be explored in a follow-on project, 'Transforming smallholder food systems in the Eastern Gangetic Plains' (WAC/2020/148), which commenced in November 2021. The project will build on work done in ACIAR SDIP to define the processes and practices (technical options, scaling interventions, policy settings and implementation) that can be applied to achieve sustainable, efficient, diversified food systems at scale in the Eastern Gangetic Plains.

A Appendix A: Partnership approaches with DFAT and portfolio partners

At the initiation of SDIP, a formal partnership agreement was collaboratively developed and signed between DFAT and ACIAR. This was a new approach for both partners, and ACIAR has learned lessons for future relationships. Annual health checks were attended by DFAT and the ACIAR SDIP team to reflect on the partnership arrangements and identify areas for improvement. Major items considered were:

1. **Processes to support the partnership approaches.** Research partnership has been the core ACIAR business model for decades. ACIAR processes are in general partnership oriented and continue to evolve with the changing national and international institutional and policy landscapes.
2. **Broader organisational engagement and uptake of the portfolio and partnership approaches.** In ACIAR there was good awareness of the DFAT/ ACIAR partnership approach for South Asia among the research programs – Land and Water, Crop Improvement and Management, and Agricultural Development Policy research programs working in South Asia. There has been interest in the approach as has been expressed by other research program managers co-investing with DFAT in other regions. ACIAR management was interested in learning from the pilot partnership. Partnership agreements are relatively young in the organisation and this program has tested whether this kind of partnership is sustainable.
3. **Linkages and collaboration with SDIP partners and beyond.** In the broader SDIP program, ACIAR had interactions with SDIP portfolio partners CSIRO, Consumer Unity & Trust Society International, the International Centre for Integrated Mountain Development and the Asia Foundation as desired by DFAT through both formal collaborative projects and regular interactions by attending meetings and joint forums. Close links with other ACIAR programs were built with complementary research designs which provided additional resources and knowledge to the ACIAR SDIP program.
4. **Institutional strengthening.** In ACIAR, partnership processes are evolving and the ACIAR SDIP program experience feeds into this. There is also significant innovation of research and scaling methods and practice on the ground, which spills over to other projects. Examples include innovation platforms, network analysis, local-level private sector engagement modalities, and multidisciplinary team engagement outside traditional research partners.

5. **Taking advantage of the flexible funding.** Flexible funding – as made possible by the partnership agreement – was used in the ACIAR SDIP program for the formulation of both Phases 1 and 2. From a field-level program (Phase 1) to a broader food systems program (Phase 2), that flexibility allowed the program to respond to emerging issues and gaps with multidisciplinary skill sets and small research activities, which proved to be a major benefit to ACIAR under the partnership approach.
6. **Mutual benefit.** In ACIAR, many aspects of SDIP are considered highly relevant to the South Asian research and development partnerships, including regionality, food-energy-water nexus, multidisciplinary partnerships, and gender.
7. **Partnering skills and competencies.** In ACIAR, competency and experience with managing partnerships is an important criterion for research program managers, regional office staff and ACIAR SDIP team recruitment. The ACIAR research program managers and regional office staff have received refresher training in partnership management.

B Appendix B: Steering Committee members

Table 3 Steering Committee members, with country and area of expertise

Member	Area of expertise	Country	Organisation	Food/Agriculture	Nutrition	Water	Energy	Gender
Professor Ramesh Chand Representative – Dr Shivendra Shrivastava	Policymaker, research analyst	India	Niti Aayog					M
Dr Pramod Joshi	Policy Adviser, Policy research analyst	South Asia	International Food Policy Research Institute, South Asia					M
Professor Saraswati Raju	Academic	India	Jawahar lal Nehru University, India					F
Dr Wais Kabir	Policymaker and research funder	Bangladesh	Krishi Gobeshona Foundation					M
Ms Farah Kabir	Development sector	Bangladesh	Actionaid					F
Mr Madhav Belbase	Policymaker	Nepal	Water Resources Division at Water and Energy Commission Secretariat, Nepal					M
Dr Aditi Mukherji	Research for development	Nepal and South Asia	International Centre for Integrated Mountain Development, International Water Management Institute					F
Dr C Suvarna	Policy implementation	India	Chief Executive, National Fisheries Development Board, Govt of India					F

continued

Table 3 *continued*

Member	Area of expertise	Country	Organisation	Food/Agriculture	Nutrition	Water	Energy	Gender
Dr Prabhu Pingali/Dr Bhaskar Mittra	Policy analyst and research for development	India and global	Tata-Cornell Institute, Cornell University, USA					M
Dr Vikas Goswami	Private Sector corporate social responsibility	India	Boundless Solutions					F
Professor Andrew Campbell	Research for development	Global	ACIAR					M
Dr Eric Huttner	Research for development	Global	ACIAR					M
Dr Robyn Johnston	Research for development	Global	ACIAR					F

C Appendix C: Publications

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