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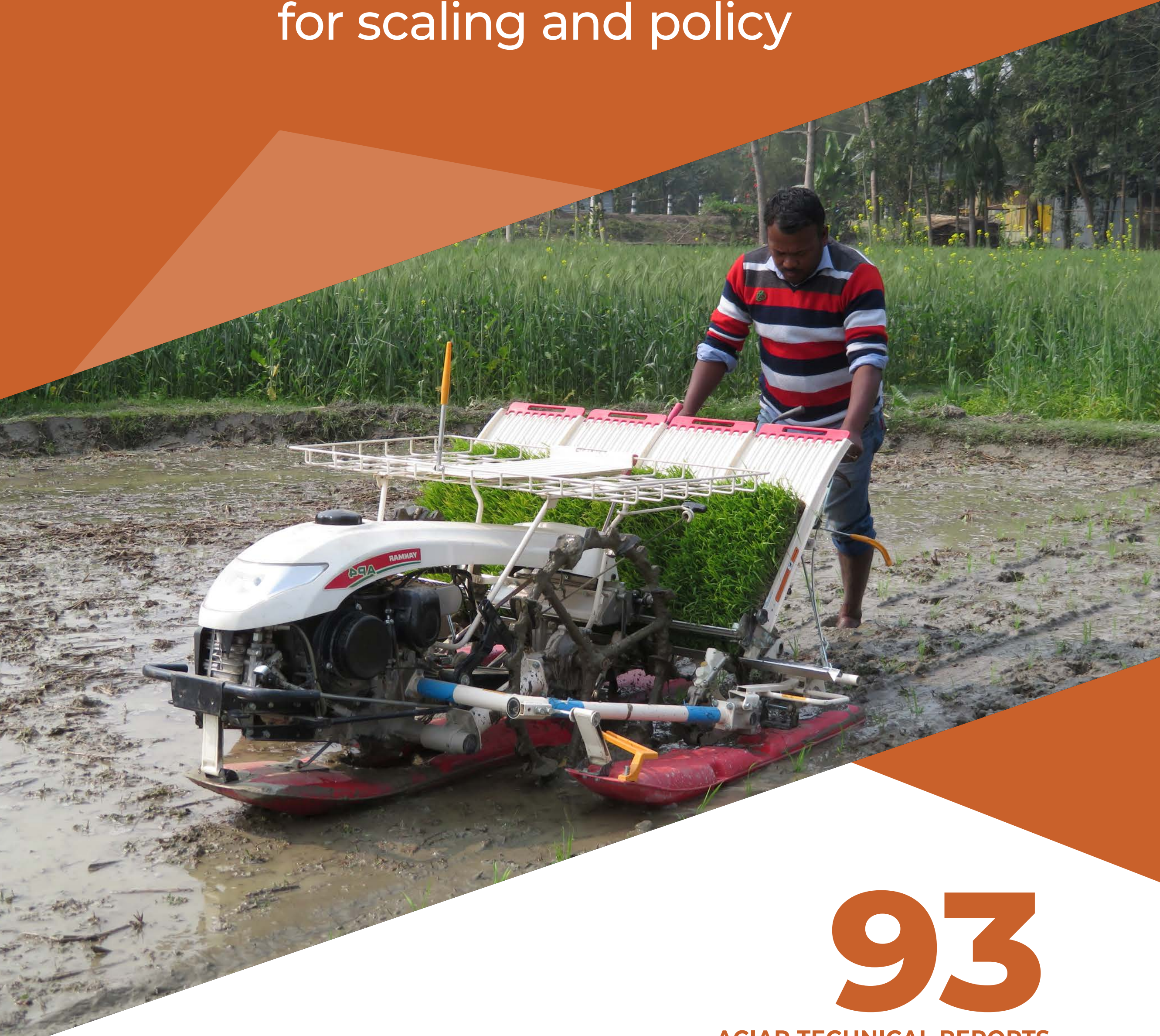
Implications of conservation agriculture–based sustainable intensification technologies for scaling and policy



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ACIAR TECHNICAL REPORTS

Implications of conservation agriculture–based sustainable intensification technologies for scaling and policy

Synthesis of SRFSI phase 1 socioeconomic studies (2012–17)

Peter R Brown, Toni Darbas, Avinash Kishore, Maria Fay Rola-Rubzen, Roy Murray-Prior, Md Mazharul Anwar, Md Shakhawat Hossain, Md Nur-E-Alam Siddquie, Rashadul Islam, Mamunur Rashid, Ram Datt, Ujjwal Kumar, Kausik Pradhan, KK Das, Tapamay Dhar, PM Bhattacharya, AK Chowdhury, A Ghosh, Bibek Sapkota, Dinesh Babu Thapa Magar, Surya Adhikari, Dipendra Pokharel, Fraser Sugden, Panchali Saikia, Sanjiv de Silva, Niki Maskey, Sofina Maharjan, Mahesh Gathala and TP Tiwari

ACIAR

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Cover: Demonstration of a rice transplanter at an information exchange event as part of the SRFSI project, Cooch Behar, West Bengal, 2018. Photo: Peter Brown, CSIRO

Foreword

Conservation agriculture-based sustainable intensification (CASI) focuses on increasing the productivity of the rice and wheat farming systems characteristic of the Eastern Gangetic Plains (EGP) in the Indian states of Bihar and West Bengal, Nepal's eastern Terai plains and north-west Bangladesh. The EGP is home to around 300 million of the world's poorest people, most of whom are farmers. Agricultural productivity is thus central to improved livelihoods for these people.

The Australian Centre for International Agricultural Research (ACIAR) is mandated by the ACIAR Act (1982) to work with partners across the Indo-Pacific region to generate the knowledge and technologies that underpin improvements in agricultural productivity, sustainability and food systems resilience. We do this by funding, brokering and managing research partnerships for the benefit of partner countries and Australia.

The Sustainable and Resilient Farming System Intensification (SRFSI) project aims to develop and promote CASI on the alluvial EGP. The project—led by the International Maize and Wheat Improvement Center—is funded through ACIAR and the Department of Foreign Affairs and Trade as part of the Sustainable Development Investment Portfolio. This project started in 2014 and has been highly collaborative, involving more than 20 institutions across Nepal, Bangladesh, Bihar and West Bengal, along with several Australian and international research agencies.

Conservation agriculture has revolutionised cropping systems in Australia over the past 40 years. It is an umbrella term for farming systems that eliminate ploughed fallows (and subsequent soil erosion and loss of soil fertility, organic matter and structure) by retaining crop residues and sowing the next crop into the stubble of the previous crop, using specially adapted seeding machinery. It usually also involves incorporating legumes into crop rotations to improve soil nutrient balances.

Adoption of conservation agriculture in Australia is now so widespread that it is rare to see a farmer ploughing fallow or burning stubble. The vast dust storms that were so frequent and widespread in Australia in the 1940s are now a distant memory.

On the EGP, CASI improves yields and introduces shorter duration varieties that enable cropping intensity to be increased to three, and even four, crops per year. Mechanisation is a strong focus, specifically the introduction of conservation agriculture machinery, which can reduce inputs (labour, water, seed) while improving soil fertility by retaining crop residues. However, this is a significant change from traditional farming systems. Decades of extension research tells us that adoption of new innovations by farmers depends on the relative advantage of the innovation (does it improve yields or save money or labour?), its complexity, its trialability, and the goodness of fit with the farmer's farming system and worldview.

Widespread adoption of CASI on the EGP will only occur if the package of CASI innovations can be promoted in a way that enables farmers to see how it can work in their own situation. This requires a sophisticated understanding of the social and economic barriers to the uptake of CASI approaches.

This report brings together social and economic studies to synthesise key lessons from the SRFSI project.

Andrew Campbell
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Acronyms

Shortened term	Definition
ACIAR	Australian Centre for International Agricultural Research
CASI	conservation agriculture–based sustainable intensification
CTL/J/M/W	conventional tilled lentil/jute/maize/wheat
CTTPR	conventional tilled transplanted rice
DSR	zero-tilled direct-seeded rice
EGP	Eastern Gangetic Plains
IP	innovation platform
NGO	non-government organisation
SRFSI	Sustainable and Resilient Farming Systems Intensification
UPTPR	unpuddled transplanted rice
WEF	water–energy–food
ZTL/J/M/W	zero-till lentil/jute/maize/wheat
ZTDSR	zero-tilled direct-seeded rice

Units

Unit	Definition
₹	Indian rupee
A$	Australian dollar
h	hour
ha	hectare
kg	kilogram
km^2	square kilometre
m	metre
m^2	square metre
mm	millimetre
mm^2	square millimetre
Rs	Nepalese rupee
t	tonne
Tk	Bangladeshi taka

Summary

This report summarises and synthesises a range of relevant socioeconomic findings from phase 1 of the Sustainable and Resilient Farming System Intensification (SRFSI) project (2012–17) (CSE/2011/077) to consider the implications of conservation agriculture–based sustainable intensification (CASI) technologies for scaling and policy. An unpublished version of this report was prepared in 2017, and has been subsequently updated to 2020, although there are ongoing activities from phase 2 that will be reported separately.

The SRFSI project aims to intensify agricultural production systems for sustainability of the alluvial Eastern Gangetic Plains (EGP). The EGP span the Indian states of Bihar and West Bengal, Nepal's eastern Terai plains and north-west Bangladesh. The project—led by the International Maize and Wheat Improvement Center—is funded through the Australian Centre for International Agricultural Research and the Department of Foreign Affairs and Trade as part of the Sustainable Development Investment Portfolio.

SRFSI focuses on raising the productivity of the rice–wheat farming systems characteristic of the EGP with conservation agriculture (CA) practices. This means introducing higher-yielding and shorter-duration varieties that enable cropping intensity to be increased to three, and even four, crops per year. Farm mechanisation is a strong focus, specifically CA machinery, which can reduce inputs (labour, water, seed) while improving soil fertility by retaining and planting into crop residues. This strategy is referred to as sustainable intensification. These technologies are largely proven and uncontroversial, although they need to be adapted to the local socioecological systems within the EGP. Together, these are referred to as CASI technologies.

Conservation agriculture–based sustainable intensification technologies and the water–energy–food nexus

CASI technologies are not a tightly defined package of fixed practices. The term refers to related and linked integrated farming actions that create synergies across outputs towards sustainable intensification of crop production. In addition to improving soil health and water use efficiency, CASI aims to reduce tillage and burning of crop residues. CASI innovations can also be used to address water–energy–food (WEF) nexus concerns.

WEF analysis supports managing trade-offs (i.e. conflicts) and achieving synergies between the water, energy and food sectors. Nexus thinking attempts to prevent a crisis in one sector being shifted to another sector due to the unintended consequence of policies. The WEF challenge facing the EGP is how to increase food production while decoupling food production from water and energy use intensity.

WEF synergies can be pursued by tightening efficiencies in water and energy use while closing yield gaps and supporting cropping intensification. These efficiencies depend on user-pay settings for energy and water, and could involve:

- replacing regular pumps with more energy-efficient or solar pumps

- increasing 'crop per drop', and using a less thirsty third crop in the rice–rice and rice–wheat systems
- promoting affordable laser land-levelling services to increase water use efficiency
- improving the energy efficiency and efficient use (e.g. single pass) of CA machinery.

It is important to explore options through which farmers can grow more crop with less water. These include planting drought-resistant crops or vegetables, building on farmers' indigenous knowledge, and refining technology-heavy interventions, such as zero tillage, and other CA techniques, such as laser land levelling.

Agriculture under CA principles can improve soil health, reduce water use and irrigation, reduce energy use and increase yields through even more uniform plant stands. Using CASI technologies (e.g. zero-tillage seed drill) improves yield, lowers production costs and therefore improves income and profits.

The SRFSI project has introduced, tested and promoted CASI-based machinery such as zero-tillage multicrop planters for crop cultivation. These are not only environment friendly, but can also help farmers save the cost, labour and energy while growing crops. Yield benefits can be up to 15% higher, and costs 30% lower, than conventional tillage. However, it needs to be applied appropriately, and there are issues such as timely planting, nutrient management, plant establishment, lodging and soil moisture issues. Poor yields are associated with poor availability of herbicides and balanced fertilisers, poor herbicide and fertiliser management, and high water prices (affecting affordability and management) or inadequate irrigation.

Zero-tillage seed drills have saved time, drudgery and farm labour. They have also helped women and other farmers to engage in other income-generating activities as well as household chores, due to the time saved. Timely operation is important, as are crop rotations, use of quality seeds, and integrated nutrient, pest, weed and water management with minimum or no disturbance to the soil. Zero-tillage seed drills has also helped subsequent crops because soil moisture is retained and water use efficiency is better (15–20% water savings). CASI has encouraged and facilitated timely cropping because the introduction of shorter-duration varieties means crops can be mature 1–2 weeks earlier and provide opportunities for intensification and diversification, which can increase farm income and crop diversity. Furthermore, zero-till systems are more climate-resilient; in bad years, the yield loss is less in zero-till systems than in conventional tilling systems.

However, there are barriers to uptake or adoption of CASI technologies, such as through:

- barriers to irrigation access. Yield is fundamentally affected by whether the farmer owns their pumping equipment. Households have variable capacity to access irrigation equipment because ownership remains with a small number of larger landowning middle and large farmers. The high price of irrigation water due to diesel-pumping costs makes irrigation unaffordable and non-profitable, which is one of the major concerns in Bihar and Nepal.
- low productivity and high costs. Productivity of staples is very low in Bihar and Nepal, and average cost of production (in dollars per quintal) is high. However, because India offers subsidies, rice and wheat growers in Nepal find it difficult to compete with neighbouring farmers. Within India, farmers can access more generous subsidies in the Indo-Gangetic Plain

- states of Punjab and Haryana, such as free electricity
- male labour migration and land tenure (outlined in 'Socioeconomic constraints').

Socioeconomic constraints

The agroecological conditions of the eight SRFSI districts do not fully explain the low levels of agricultural production and productivity. This makes it necessary to understand how the institutional settings characterising the eight districts discourage increased production. Much stronger public and private sector services are available to Indian farmers on the Indo-Gangetic Plains compared with all of the EGP jurisdictions. Differences also exist between the participating districts in terms of services and infrastructure; in particular, Nepal's Dhanusha district and Bihar's Madhubani district lack all forms of agricultural services and infrastructure. The multiple constraints confronting the EGP's resource-poor farming households can be explained by four institutional factors:

- limited public services and dominance of small, informal enterprises
- strong coupling between irrigation access and land tenure
- poor coordination between agricultural research and development agencies
- male labour out-migration and the feminisation of agriculture.

The main socioeconomic constraints confronting EGP smallholder and tenant farmers are connected, and include:

- *small land size and landlessness*. Landholding sizes in the region are very small, even by South Asian standards, and property rights are poorly defined, including sharecropping laws. Thus, most of the farmers in the region have small input requirements, less purchasing power and small marketable surplus. The cost of dealing with large numbers of small, poor and female farmers is high. Furthermore, food security is entangled with caste and tribal identities and their relative socioeconomic status within (rapidly eroding) strict social hierarchies. Land redistribution is an incomplete solution to this problem. Land is tightly held and highly fragmented across the EGP. Improving the security of tenants through registration and improving the terms of sharecropping seem more promising avenues for households with no land or insufficient land to meet their subsistence needs. The more landless households there are, the more landlords can extract from agricultural labourers, sharecroppers and tenants. Small and fragmented land sizes pose difficulties in identifying appropriate technologies and ensuring that small farms can access them. Tenants struggle to deal with absentee landlords or negotiate reasonable terms for renting or sharecropping land
- *high rates of poverty in the EGP, which is 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
- *low incomes*. Beyond household food security, a disposable income is needed to buy food that is not produced on-farm, and to purchase services such as education, health and other basic necessities. It is important to develop off-farm income sources
- *access to credit reduced under economic liberalisation since the 1990s*. However, women's self-help groups and men's farmer groups and clubs can be effective ways to increase institutional credit provision to the impoverished, as shown

in Bihar and West Bengal. The situation is improving through the Kisan Credit Card scheme, which facilitated the easy access of credit from banks in India, but can be accessed only by those who own land

- India's *Mahatma Gandhi National Rural Employment Guarantee Act* (MGNREGA) and, throughout the EGP, male labour out-migration are important livelihood strategies for the rural poor. They provide a source of cash income that supplements other on-farm and off-farm income sources, but can also entrench subsistence agriculture, as income is usually invested in consumer goods, health care and schooling
- *high rates of migration*. Male labour out-migration provides an important supplemental income for rural households, which is pivotal to household food security. But, it also causes farm labour shortages. The increased cost of employing farm labourers has increased demand for labour-saving farm machinery. Widespread male circular and overseas labour migration inevitably alters gender relations, as the everyday decision-making that farming women who are left behind are forced to take over incrementally loosens patriarchal social structures (see next point). The process is complex, because gender identity intersects with other aspects of identity such as caste, class, marital status and age
- *feminisation of agriculture*. Women are in more demand as farm labourers and managers of their own household's farming operations. Although making agricultural decisions could economically empower rural women, public extension systems do not cater for them. Feminisation of agriculture has not equally occurred across the EGP. Feminisation in Nepal and Bangladesh is consistent with expected trends, but defeminisation appears to be occurring in Bihar and West Bengal. This could be related to several factors, including higher levels of unemployment, lack of jobs and increased remittances (meaning women do not need to work). Either way, resource-poor women need to be empowered
- *poor extension systems*. The extension agent to farmer ratio is low, and is symptomatic across the EGP. Fostering linkages to research universities and institutes, and non-government organisations (NGOs) can be a viable model to strengthen public extension systems by getting adapted technologies to farmers and making sure farmers are aware of their entitlements
- *poor infrastructure and poor connectivity* (roads, power, credit, markets) raises the cost of doing business even higher
- *geographic disadvantages*. The region—especially the SRFSI locations—have low rates of urbanisation and are far from major urban markets or ports
- *different farmer types*. It is important to consider 'farmer typologies' to recognise that not all farmers are the same. They will not respond to CASI technologies the same, or have the same capacity to adopt them. It is also important to consider gender roles and look for opportunities for equity.

These constraints vary by district. Bangladesh has the most enabling institutional environment, and Bihar's Madhubani and Nepal's Dhanusha districts the least enabling institutional environments for CASI uptake. However, Bangladesh has reached its ecological limits to further intensification.

Opportunities for scaling and policy

A farmer in the EGP depends almost entirely on small-scale private parties (i.e. intermediaries) to secure an often limited range of agricultural inputs and to market produce surplus. Given the ubiquity and the predominance of small and localised businesses in the agrarian economy of the EGP, it is essential to work with small-scale private players for scaling-out CASI technologies. Large organised private enterprises (e.g. agribusinesses such as Monsanto) and medium enterprises do not invest in the EGP region. Some form of aggregation is required to increase farmers' bargaining power in the market and reduce companies' cost of doing business with them. Increasing productivity is essential, to reduce the cost of production and to generate enough marketable surplus at the local or regional level.

Addressing these constraints will require structural changes in how resources are accessed. Group ownership of irrigation and farm mechanisation equipment provides the most promising short-term solution for marginal and tenant farmers, and will build on successful state and non-state interventions in the region. It is also, however, critical to continue to pursue options of more water-efficient farming (however, if water and/or power is underpriced it will be overused), which is even more important in an era of climate change. Making effective use of indigenous knowledge relating to water-efficient crops, while using CA techniques such as zero tillage and crop diversification, combined with cooperative land and water use, can provide a framework for an integrated model of farming for the future.

Other approaches required include the following:

- Support community business facilitators (CBFs). The CBFs are a good model, but facilitators need training and support. They also need a good business model so they get financial benefits. When CBFs work well, adoption of zero tillage is higher. CBFs only work where there is already an effective business model—it is not a standalone method.
- Support a range of business models, including seed production groups, CASI equipment hub hire centres in nodes, marketing companies, subcontractors, village-based input shops, agricultural clinic or input shops, and convergence with national flagship programs.
- Encourage private sector interest. Agricultural intensification itself attracts private sector interest, but the corporate sector prefers larger markets or areas that grow (or demand) niche products.
- Improve extension services. NGO expertise in upliftment and empowerment could be used to develop the capacity of marginalised farmers to negotiate contracts, land access and niche markets. Up-front investment in capacity building can deliver new frontline extension services, such as the outreach that farmers clubs have achieved.
- Improve access to credit. Women's self-help groups and men's farmer groups and clubs can be an effective way to increase institutional credit provision to the impoverished. A group can access credit to purchase CASI equipment. The lender uses group assets and effective group governance as a criteria. Good group governance needs to be a condition of group-based subsidy and credit provision methods. Partnerships with women-centric NGOs to provide services in situ to bypass the mobility

constraints on women cultivators are proven methods, which could be extended through financially sustainable business models.

- Explore whether land tenure and sharecropping arrangements could be made more equitable and profitable. Some form of aggregation is needed (such as producer companies, joint liability groups), given small holdings and small marketable surplus. A paradigm shift from land rent to machine rent (although this will largely benefit rich farmers all the time) is needed.
- Better overall water security including well-developed and low-cost water markets, and better long-term state investments are key explanatory factors. As groundwater further depletes, particularly in Bangladesh, use of deep tube wells will depend on factors such as the nature of the aquifer, future cropping intensities and their water demand.

Relevant policies

The current relevant policies for CASI adoption in the region include:

- policies for pricing power supply to farmers—flat-rate, subsidised unit-rate, full-cost pricing
- policies related to import of agricultural equipment—importation is allowed in Bangladesh but restricted in India and Nepal.
- subsidy and targeting policies on the CA equipment—heavy but poorly targeted and poorly designed capital subsidies exist in India. Better designed subsidies will help scaling-out (e.g. drip irrigation in Gujarat)
- policies related to marketing of agricultural produce—poor market infrastructure, and tariff and non-tariff barriers on moving agricultural commodities exist.

1 Introduction

The Eastern Gangetic Plains (EGP) region has the highest rates of rural poverty worldwide. There is therefore a dire need to improve agricultural production and productivity in this region to enable or sustain household, regional and national food security. Regional demographic challenges include:

- high rates of population growth
- a large youth population
- male labour out-migration to urban areas (India) and South-East Asian and Middle East countries (Bangladesh and Nepal).

Regional natural resource challenges include groundwater depletion, pollution and inefficient use of water and energy. To address these issues, a holistic approach is needed to identify relevant environmental, economic and social aspects of increasing agricultural production and productivity.

The Australian Government Department of Foreign Affairs and Trade (DFAT) funds the Sustainable Development Investment Portfolio (SDIP), which focuses on South Asian river basins. As a project within SDIP, the Sustainable and Resilient Farming System Intensification (SRFSI) project will help review the nexus between water–energy–food (WEF), which frames the SDIP. WEF analysis involves identifying system-wide trade-offs and synergies between water, energy and food (Gathala et al. 2020a; Hoff 2011). It also identifies pathways for sectors to effectively coordinate their efforts towards sustainable management of water, energy and food.

The SRFSI project aims to intensify agricultural production of the alluvial EGP that span the Indian states of Bihar and West Bengal, Nepal's eastern Terai plains and north-west Bangladesh. Australia's Aid Program, through the Australian Centre for International Agricultural Research (ACIAR) and DFAT, funds the project, and it is led by the International Maize and Wheat Improvement Center.

SRFSI focuses on increasing the productivity of rice and wheat farming system—which are common in the EGP—by using conservation agriculture (CA) practices. CA means using higher-yielding and shorter-duration crop varieties that enable cropping intensity to be increased to three, and even four, crops per year. CA focuses on farm mechanisation, specifically, introducing CA machinery that is able to reduce inputs (labour, water, seed) while improving soil fertility by retaining and planting into crop residues (Gathala et al. 2020a, 2020b; Islam et al. 2019; Sinha et al. 2019). This strategy is referred to as sustainable intensification (SI). These technologies are largely proven and uncontroversial, although they need to be adapted to the local socioecological systems within the EGP. Together, SI and CA are referred to as conservation agriculture-based sustainable intensification (CASI) technologies.

CASI technologies are not tightly defined, fixed practices (Andersson & D'Souza 2014; Brown, Llewellyn & Nuberg 2018). More often, the term denotes related and linked integrated farming actions that create synergies across outputs towards SI of crop production. In addition to improving soil health and water use efficiency, CASI aims to reduce tillage and crop residue burning. CASI innovations can be used to address the links among WEF. During phase 1 of SRFSI (2012–17), CASI has been piloted in 40 village nodes within eight districts across north-east India, the Terai of Nepal and north-west Bangladesh, to inform the local context, which can be used to guide strategies for wider adoption.

SRFSI phase 1 has included several activities and reports that engage with the social and economic contexts of the project across the EGP. Phase 1 activities and reports provide context for ongoing work to be reported separately. This report gathers, consolidates and integrates the key findings. We explore the lessons learned and how they can be used to guide future activities and investment.

Brief history and context of the Eastern Gangetic Plains

The socioeconomic make-up of the EGP is complex, with a range of agroecological systems, livelihood strategies, farm sizes and tenure types, and access to technologies and institutions. The historical co-evolution of farming systems and agrarian socioeconomic structures has differentiated states and nations out of what was originally one Bengali region. Famine and food insecurity have featured for centuries in the EGP region, have shaped the contours of the EGP's modern jurisdictions and are deeply ingrained on the psyche of farmers and policymakers. The EGP jurisdictions today are in varying degrees of transition from feudal, agrarian socioeconomic structures, and of integration into the global economy. The following is a review of the history of the EGP to introduce the key biophysical, institutional and socioeconomic constraints facing smallholder and tenant farmers to widespread adoption of CASI technologies.

India

India is a large democracy with a rapidly modernising and globally integrated economy. The Green Revolution was instigated in the 1960s to address food insecurity in the Indo-Gangetic Plains in the country's north-west, which enabled national food grain self-sufficiency by the 1970s. Post-independence, in 1947, those in poverty were constitutionally designated as belonging to backwards castes and tribes, issued with entitlement cards and provided with targeted welfare nets in the form of subsidised employment and food grain. However, corruption in the procurement and distribution of food grain, access to and payment for work and access to below-poverty-line cards have plagued these programs (Banerjee et al. 2014; Darbas et al. 2013).

Partially successful land reforms in West Bengal, a result of peasant movements after the Bengal famine, have had the side effect of increasing land fragmentation and infertility. Bihar was considered the most politically regressive state until a pro-development government in 2005 restored law and order (Singh & Stern 2013). India has maintained tight controls on trade and provides substantial support to its agriculture sector in the form of subsidies—for example, on fertilisers. Nonetheless, in the north-eastern Indian states of Bihar and West Bengal, male out-migration to better renumerated urban labour markets reflects widespread household food insecurity and has resulted in the feminisation of agriculture and farm labour shortages (Darbas et al. 2020; Lahiri-Dutt 2014).

Nepal

Nepal is situated between India and China, and its land is 77% hills and mountains.

It has a long and ambiguous history of political sovereignty. Present unified Nepal was ruled by several Saha kings for more than 200 years until a people's movement abolished the monarchy in 2006. In the 1960s and 1970s, marginalised socioeconomic groups deforested and colonised the Terai plains after malaria was eradicated. An armed insurgency subsequently occurred throughout the country from 1996 until a peace agreement was negotiated in 2006. Altercations between authoritarian and democratic regimes have resulted in the promulgation of a federal constitution in 2015 mandating the establishment of provinces, followed by legislative elections in 2017.

Most trade is with India, and a significant part of it is unofficial because the border between the two countries is open. Markets were liberalised under international structural adjustment terms in the 1990s, but failed to lift production in the Terai, which remains at subsistence levels. Nepal's agriculture sector is still struggling to achieve significant growth in yields and land productivity. The yields of staple crops such as rice and wheat in Nepal are low compared with other parts of South Asia where the rice–wheat system is dominant. The major limiting factors for the growth of the agriculture sector in Nepal are considered to be:

- poor access to, and use of, improved agricultural technologies and inputs, including low levels of farm mechanisation and agricultural infrastructure and support services
- the dominance of small and fragmented holdings
- the persistence of a traditional, rain-fed farming system.

Additionally, the acute labour shortage and feminisation in agriculture resulting from increasing out-migration of young men to international labour markets, rises in food and labour prices, and climate change impacts have further undermined agricultural development in Nepal (Darbas et al. 2013; Lahiri-Dutt 2014). A new federal structure was implemented in Nepal after the adoption of the constitution in 2015, and as such the research work presented here was largely done before the implementation of the new federal governance structure.

Field trial of zero-tilled maize sown in 2014 at Ghughumari, Cooch Behar, West Bengal, India. Photo: Peter Brown, CSIRO

Bangladesh

Bangladesh emerged as a nation in the early 1970s as a result of a war of independence from west Pakistan and was immediately plunged into famine. Market liberalisation policies under structural adjustment settings throughout the 1980s helped the new nation to kickstart a Green Revolution in the 1990s that achieved national food grain self-sufficiency by 1995. This was due to the rapid mechanisation of tillage and other agricultural operations, concerted irrigation development and high use of high-yielding varieties. Agriculture remains one of the most important sectors of the Bangladeshi economy, contributing 14.75% to the national gross domestic product in 2015–16, although remittances from international labour migrants are just as significant. Rapid population growth has eroded these achievements, while the agriculture production rate has been relatively steady. Every year, the population increases while agricultural land shrinks by about 0.08 million hectares. Currently, about 45.1% of the labour force is engaged in agriculture, but significant seasonal labourer scarcity and increasing labour wages have led to increasing production costs (Darbas et al. 2013).

Sustainable and Resilient Farming System Intensification districts

The SRFSI project operates in eight districts (Figure 1.1). Two districts were selected from each of the four jurisdictions comprising the EGP:

- the Indian states of Bihar (Madhubani and Purnea) and West Bengal (Cooch Behar and Malda)
- north-western Bangladesh (Rangpur and Rajshahi)
- the eastern Terai of Nepal (Dhanusha and Sunsari).

These districts were selected to represent the diversity of communities and farming systems targeted for CASI uptake. Table 1.1 summarises the major indicators and the following sections describe the key statistics for each district.

Source: Wikipedia (https://commons.wikimedia.org/wiki/File:Ganges-Brahmaputra-Meghna_basins.jpg)

Figure 1.1 Map of the Eastern Gangetic Plains showing the districts of the Sustainable and Resilient Farming System Intensification project

Table 1.1 Key socioeconomic indicators of countries and regions under study

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

Source: Aryal & Maharjan (2015)

West Bengal

Cooch Behar district is 3,387 km^2 (IWMI 2016a) and has a population of 2,822,780, of which 48.5% are female. The district is 61–610 metres above sea level. It has a tropical climate that is hot, wet and moderately humid, with annual average temperatures ranging from 3.9 °C to 39.9 °C. Monsoonal rains fall between June and September, with an average annual precipitation of 3,201 mm. The land is mainly of alluvium with sandy/clayey texture. The district's cultivated area is 253,063 ha, of which 76,949 ha is irrigated. The main crops (by planted acreage) grown are rice, wheat, maize, pulses and potatoes. The main cropping patterns are paddy–paddy, paddy–wheat–jute, paddy–maize, paddy–lentil and paddy–potato–paddy/maize. The productivity of the major crops is paddy 2.84 t/ha, wheat 2.37 t/ha and maize 4.79 t/ha.

Malda district is 3,733 km^2 and has a population of 3,988,845, of which 48.6% are female (IWMI 2016d). The district sits 0–56 metres above sea level. It has a subtropical climate with average annual temperature ranging from 9 °C to 43 °C. Average annual rainfall is 1,453 mm, falling mainly during June to October. Malda comprises unfertile alluvial soil in Barind and fertile plains alluvial soil in Diara. The total cultivable area is 280,000 ha, of which 144,588 ha is irrigated. Currently, 23%, 50% and 18% of the land area is single, double and continuously cropped, respectively, and 9% of the land area is uncultivated. Overall, cropping intensity is 196%, with major crops grown as rice, wheat, legume, maize and jute. The main cropping patterns include paddy–wheat, paddy–mustard–jute, paddy–mustard–maize, paddy–lentil, paddy–maize, and paddy–mustard–paddy. The productivity of major crops is paddy 4.64 t/ha, wheat 3.72 t/ha and maize 7.69 t/ha.

Bihar

Madhubani district is 3,501 km^2 and has a population of 4,487,379, of which 48.1% are female (IWMI 2016c). Madhubani district is basically a low-elevation flat plain (47–90 metres above sea level), with a subtropical to tropical climate. The average annual temperature ranges from 10 °C to 36 °C. The average annual rainfall is 1,289 mm, which falls mainly during July and August. Madhubani district comprises alluvial soil of Terai. The total cultivated area is 218,381 ha, of which 138,551 ha is irrigated. The major crops grown are rice, wheat, maize, pulses and potatoes. The main cropping patterns include paddy–wheat, paddy–pulse, paddy–vegetable and paddy–mustard. Currently, 19%, 55% and 23% of cultivated areas is single, double and continuously cropped, respectively, and rainfed areas occupy 2% of cultivated area. The crop productivity is low—paddy 2.08 t/ha and wheat 2.16 t/ha.

Purnea district is 3,202 km^2 and has a population of 3,264,619, of which 48% are female (IWMI 2016e). Purnea is a flat plain area with a low elevation (0–58 metres above sea level) and a subtropical to tropical climate. The average annual temperature ranges from 30 °C to 48 °C. The average annual rainfall is 1,470 mm falling mainly during June to September. Purnea comprises loamy alluvial soil. The total cultivable area is 254,885 ha, of which 240,213 ha is cultivated. Major crops grown are rice, wheat, legume, mustard, maize, jute and banana. The common cropping patterns include paddy–wheat, paddy–potato–maize, paddy–mustard and paddy–maize. Currently, 23% and 72% of the land area is double and continuously cropped, respectively, 4% of the land area is uncultivated and only 1% is single cropped. The crop productivity is low—paddy 2.99 t/ha and wheat 2.39 t/ha—except maize which yields 6.39 t/ha.

Nepal Terai

Dhanusha district is 1,180 km^2 and has a population of 754,777, of which 51% are female (IWMI 2016b). The topography of the district is 60–600 metres above sea level, with a semiarid to tropical climate. The average annual temperature ranges from 11 °C to 30 °C. The annual average rainfall is 1,480 mm, mainly during June to September. Dhanusha has alluvial soil. Of the total cultivable area of 76,531 ha, 68,880 ha is cultivated and 79.32% of this area is net irrigated. The major crops grown are rice, wheat, pulses, oilseeds and sugarcane. The main cropping patterns include paddy–wheat, paddy–pulse, paddy–lentil, paddy–oilseed and paddy–maize. Currently, 30% and 37% of the land area is single and double cropped, respectively, 30% of the land area is uncultivated and only 3% is continuously cropped.

Sunsari district is 1,281 km^2 and has a population of 763,487, of which 51.4% are female (IWMI 2016h). The district is 67–1,470 metres above sea level and has a subtropical to tropical climate. The average annual temperature ranges from 10 °C to 43 °C. The average annual rainfall is 1,943 mm, received mainly between June and September. Sunsari district mainly has alluvium soil, and is sandy to clayey in different parts of the district. Of the total cultivable area of 70,588 ha, 70,575 ha is cultivated of which 98% is irrigated. The major crops grown in the district include rice, wheat, mustard and legumes. The main cropping patterns are paddy–wheat, paddy–potato–fallow, paddy–maize, paddy–lentil and paddy–vegetable. Currently, 12%, 25% and 32% of the land area is under single, double and continuous cropping, respectively, and 31% of the land area is not irrigated. The productivity of the major crops grown is low—paddy 3.7 t/ha and wheat 2.5 t/ha.

Bangladesh

Rajshahi district is one of the north-west districts of Bangladesh within the drier northern part of the country (IWMI 2016f). Rajshahi is 2,425 km^2 and has a population of 2,595,197, of which 49.5% are female. The topography is generally flat (elevation of 10–49 metres above sea level). The climate is tropical with annual average temperatures ranging from 11.6 °C to 35.9 °C. The district receives medium annual monsoonal rains of about 1,524 mm. The soil is generally loamy to clayey. Of the total land area, 189,399 ha is cultivable, of which 63% is irrigated. The current cropping intensity is 202%. The major economic crops grown are rice, wheat, potato, jute, maize, mustard, sugarcane and vegetables. These are grown mainly on double-cropping patterns, as paddy–pulse, paddy–wheat, paddy–maize, paddy–mustard–paddy and paddy–potato–maize. Self-owned farm land dominates the farming land in the district (60%), and mixed owner-cum-tenant and pure tenancy comprising 35% and 5% of the cultivated land, respectively. Crop productivity is generally high, with paddy yields of 3.46 t/ha, wheat 2.20 t/ha, maize 6.97 t/ha and potato 24.2 t/ha.

Rangpur district is 2,326 km^2 and has a population of 2,881,086, of which 49.9% are female (IWMI 2016g). The topography ranges from 22 to 41 metres above sea level. The district is characterised by a tropical hot wet and humid climate, with annual average temperatures ranging from 6.0 °C to 36.3 °C and an average annual rainfall of 2,931 mm. The soils are generally either low-fertility Barind Tract or fertile alluvial ‘poli’. The total cultivable area is 179,687 ha, of which 179,282 ha is cultivated. The average cropping intensity is 224%, and the main crops are rice, wheat, potato, jute, maize, mustard and vegetables. The cropping extent is 1%, 86% and 5% for single, double and continuously cropped, respectively, with 8% of the land uncultivated. Common cropping patterns are paddy–paddy, paddy–potato–maize, paddy–maize, paddy–wheat, paddy–wheat–jute and paddy–potato–paddy. Average crop productivity is paddy 3.46 t/ha, wheat 2.20 t/ha, maize 6.97 t/ha and potato 24.2 t/ha.

Four-wheel tractor with trailer driving on an unsealed rural road near a flowering mustard crop, Dhanusha, Nepal, 2015. The number of tractors available for use in the fields and for other uses such as haulage is increasing in all areas. Photo: Peter Brown, CSIRO

2 Key production constraints

The agroecological conditions of the eight Sustainable and Resilient Farming Systems Intensification (SRFSI) districts do not fully explain the low levels of agricultural production and productivity detailed in the district summaries in Chapter 1. Therefore, we need to understand how the institutional settings of the eight districts discourage increased production. Much stronger public and private sector services are available to Indian farmers on the Indo-Gangetic Plains compared with the Eastern Gangetic Plains (EGP) jurisdictions. There are also differences between the participating districts in terms of services and infrastructure, in particular, Nepal's Dhanusha district and Bihar's Madhubani district lack all forms of agricultural services and infrastructure. Four institutional factors can explain the multiple constraints (Table 2.1) confronting the EGP's resource-poor farming households:

- limited public services and dominance of small, informal enterprises
- link between irrigation access and land tenure
- poor coordination between agricultural research and development agencies
- male labour out-migration and the feminisation of agriculture.

Table 2.1 Key production constraints

Country or region	Climatic constraints	Biological constraints	Socioeconomic constraints
Bangladesh	Drought, heat stress, rain, flood	Disease, pest and weed intensification	No availability of labour, machinery and skilled human resources for operating machinery; financial crunch
Bihar	Drought, heat stress, flood, hailstorm	Disease, pest and weed intensification, degradation of soil quality	No availability of labour, irrigation, machinery, electricity, inputs and credit
West Bengal	Drought, heat stress, rain, flood	Disease, pest and weed intensification, groundwater depletion	No availability of skilled human resources, machinery and quality inputs; difficulties in accessing credit, market (input and output) and irrigation
Nepal	Drought, heat stress, erratic rainfall, hailstorm	Disease, pest and weed intensification, degradation of soil quality	No availability of inputs, skilled labourers, irrigation, credit, electricity; poor marketing networks; high input prices; lack of access to services

Source: Aryal & Maharjan (2015)

Limited public services and dominance of small, informal enterprises

The agriculturally oriented public sector in the EGP has limited capacity and reach. Farmers in the region, unlike in many other parts of South Asia, have limited interactions with government agencies in running their farm enterprise. For example, a typical farmer in Indian Punjab in the western Indo-Gangetic Plains depends directly on government for irrigation—through canals or subsidised grid electricity that powers groundwater irrigation—purchasing quality seeds, and selling her rice and wheat at the minimum support price. She is also more likely than her counterpart in the EGP to receive crop loans (which comes bundled with crop insurance), weather advisory services and agricultural extension from government agencies (Table 2.2). A farmer in the EGP depends almost entirely on private parties for securing different agricultural inputs and selling her produce.

Given the ubiquity and the predominance of the private sector in the EGP's agrarian economy, it is essential to work with private players for scaling-out conservation agriculture–based sustainable intensification (CASI) technologies. However, organised private enterprises—even small and medium ones—were not investing in the EGP region in 2017. The Sustainable and Resilient Farming System Intensification (SRFSI) project collaborated with Prayati Skills & Resource Development Pvt. Ltd to explore opportunities for investment by large corporations in the agriculture sector in the study districts of India. After meeting with several firms who may be interested, Prayati reported that most large corporations are not planning to invest in Bihar or West Bengal. The one or two firms that showed some interest in investing in the region were considering districts other than SRFSI locations.

The EGP region in general and SRFSI locations have several disadvantages that make them less attractive to profit-seeking private companies:

- The agrarian structure. Landhold size in the region is very small even by South Asian standards. Thus, most of the farmers in the region have small input requirements, less purchasing power and small marketable surplus. Dealing with large numbers of small, poor farmers has high transaction costs.

Table 2.2 Public provisions for farmers in Bihar and Punjab

Agricultural activity or facility	Farmers who benefit directly from the government (%)	
	Bihar (EGP)	Punjab (IGP)
Electricity for groundwater irrigation	<1.0	92.9
Technical advisory by government institutions	11.5	18.3
Institutional loans for agriculture	16.5	49.2
Awareness about minimum support price	43.6	87.9

EGP = Eastern Gangetic Plain; IGP = Indo-Gangetic Plain
Source: Estimated by authors using data from the Situation Assessment Survey of Farmers by the National Sample Survey Office and primary surveys by IFPRI (2016) in Bihar and Punjab.

- Poor infrastructure. Poor connectivity makes the cost of doing business in the region even higher.
- Low productivity and high costs. Productivity of staples is very low in Bihar and Nepal, and average cost of production (in dollars per quintal) is high. As a result, rice and wheat growers in these areas cannot compete with their counterparts in neighbouring states or countries.
- Geographic disadvantages. The region (specifically, the SRFSI locations) have low rates of urbanisation and are far from major urban markets or ports.

Relatively small, informal and unorganised local players dominate the private sector in the EGP. These small entrepreneurs or service providers are ubiquitous in the region. They enjoy two distinct advantages. First, they are closer to the consumers and they have a better understanding of local farmers' needs. Second, they can avoid taxes and regulations. The informal and unorganised sector serves even the smallest farmers with the lowest requirements, understands local needs better and is highly flexible in serving those needs.

On the downside, these informal entrepreneurs have limited reach among consumers and limited ability to raise capital to expand their business. They are poorly integrated with regional and global commodity value chains and innovation streams. These small businesses provide non-innovative products or services to low-income farmers, using limited capital and adding little value. But these informal entrepreneurs are also less efficient, slower to adopt and introduce new technologies and practices in agriculture, and have limited capacity to integrate smallholder agriculture with regional, national or global value chains to secure higher returns for farmers.

As a result, farmers in the region have poor access to input and output markets and services to help them adopt appropriate technologies for increasing their productivity and incomes. Research shows that, left to their own devices, these informal firms rarely transition to formality. They continue, often for years or even decades, without much growth or improvement (La Porta & Shleifer 2014).

Given the critical role of the private sector in the agroeconomy of the EGP and the limited ability of the existing private players in the region to adopt new technologies, access new markets and evolve into more efficient enterprises, the phase 1 SRFSI project has done research to:

- better understand the private entrepreneurs and enterprises
- build the capacities of the private sector
- identify policy strategies to facilitate private sector participation in the agriculture sector.

The following tasks were done in phae 1 of the SRFSI project to strengthen the private sector in the EGP:

- First, we surveyed farmers, and machine and irrigation service providers in Bihar, West Bengal, Bangladesh and Nepal to understand the nature of the water markets and machine rental markets (i.e. their structure, conduct and performance).
- Second, we completed desk studies of policies and programs that affect private sector participation in the agriculture sector in the region.
- Third, we explored ways to collaborate with private sector partners—including local service providers, small and medium enterprises, producer organisations and even large firms—to be a part of innovation platforms (IPs) to promote CASI technologies or invest independently in commodity value chains.

Land tenure and irrigation

India is water stressed, with 78% of water used for irrigation (Gulati 2016). High subsidies on electricity in the Indo-Gangetic Plains has led to overexploitation of groundwater and is a key risk for farming intensification in the EGP. India needs to ramp up its storage capacity, since 75% of its rains fall during 120 days in June to September. It is critical for India to buffer its water stocks. The overall efficiency of water systems is 30–65% for surface-water systems and 65–75% for groundwater systems (Table 2.3).

There are various constraints to irrigation access (Shah, Singh & Mukherji 2006). The first barrier lies in household capacity to access irrigation equipment such as tube wells and pump sets. Given the unreliable flows of surface irrigation schemes and their limited extent, groundwater is the most favoured irrigation source in the EGP. However, like land itself, ownership of pumps and tube wells remains within the hands of a small number of landowners with medium and large farms. Considerable cash investment is required. Marginal farmers often depend on expensive and monopolised pump and tube well rental markets.

Multiple factors affect the decision-making process regarding water use. Cropping intensity or investment may be higher for more marginal farmers under pressure to meet their subsistence needs, whereas others may reduce their resource allocation and leave more land fallow due to the high costs of renting equipment. Even large farmers may leave land fallow or reduce investment due to labour shortages, high input costs and the perceived unprofitability of agriculture.

Migration also poses a constraint to water access, and this particularly affects women farmers, particularly women-headed households. Faced with a high labour burden and a less regular inflow of cash, accessing money to invest in irrigation can be challenging. The more limited social networks and gender ideologies can also be constraining. Finally, migration has undermined the functioning of many irrigation management institutions, and persisting limitations on women's engagement has failed to counterbalance these changes.

Average yields are lower on rented plots across the Nepal Terai and Madhubani, but not in Purnea (which is close to a large maize market). Rangpur and Rajshahi also follow the general trend of lower yields on rented land, except for monsoon-season rice in Rajshahi. There have been concerted state-driven water supply and demand-side interventions in more water-

Table 2.3 Irrigation methods and efficiency (India)

Irrigation method	Efficiency (%)
Conveyance through unlined canal for surface water	55–60
Conveyance through lined canal for surface water	70–75
Conveyance through surface and groundwater flood irrigation	65
Furrow irrigation	80
Sprinkler	85
Drip	90

stressed Rajshahi. This appears to allow various farmers to partially overcome politicoeconomic constraints to irrigation uptake and adapt to challenging biophysical conditions. In Rajshahi, farmers are more willing to change traditional cropping practices than in Rangpur, where their focus is on multiple paddy crops and maintaining access to groundwater (Sugden et al. 2016).

Poor coordination between agencies involved in agricultural development

Across the region, constraints and entry points to smallholder farmer uptake of conservation agriculture (CA) technologies are mainly institutional. The Centre for Research on Innovation and Science Policy (CRISP) was contracted in 2014 to undertake an institutional analysis (Darbas et al. 2015) in the eight SRFSI districts by interviewing key informants. The results were then confirmed with the Bihar, West Bengal, Bangladesh and Nepal socioeconomic teams in 2015 to support establishing multistakeholder forums (IPs) that could coordinate agency efforts.

Although some good-quality CASI research has taken place, particularly in Bangladesh, it has been isolated and only had a small influence. The SRFSI project results from on-farm trials have been very positive (Gathala et al. 2020a, 2020b; Islam et al. 2019; Sinha et al. 2019). The formal publicly funded extension sector incompletely addresses the need to connect CA knowledge and expertise in the publicly funded research sector to the smallholders and sharecroppers. This is due to the low farming household to extension officer ratio. Extension and research project modalities consequently emphasise working with farmer groups to gain traction.

Thus, the varied but extensive social infrastructure of male farmer groups and clubs and female self-help groups was identified as a way to reach the EGP's smallholders and sharecroppers. Research projects, extension programs and non-government organisations (NGOs) focused on rural livelihoods built these social groups over time. However, these groups are distributed across the public, civic and private sectors; independently funded; and function in isolation. We here summarise the findings in each jurisdiction, starting in Bangladesh where agriculture is more developed and highlighting developmental differences between districts.

The CRISP analysis concluded that a strategic vision and a functional platform to exchange organisational information and learnings, and drive CASI policy and programming, is the best way forward in the four jurisdictions.

North-west Bangladesh (Rangpur and Rajshahi districts)

North-west Bangladesh became a food surplus area after separating from Pakistan. However, these gains are currently eroding in the face of high population growth and groundwater depletion. Both districts are in the upland Barind Tract, which relies heavily on groundwater using deep tube wells for irrigation and other purposes. Agricultural operations are highly mechanised, a result of the economic liberalisation policies that followed independence, which encouraged cheap imports of small-scale machinery from China. The districts have strong research institutes and NGOs, such as the RDRS (a SRFSI partner), but need to be strengthened to encourage more collaboration. The region also needs policy support for CASI technology uptake.

West Bengal (Malda and Cooch Behar districts)

West Bengal in India is characterised by a rich array of organisations relevant to CASI, but whose various endeavours are highly fragmented. There is a lack of strategic vision and a functional platform to exchange organisational information and learnings. There is little interaction among agricultural agency staff below the district level, and staff are not trained before introducing a new scheme, program or project. There are some strong community-centric and well-connected NGOs. Farmers clubs are increasingly recognised as an important platform for farmer-to-farmer interaction and knowledge transfer. However, the Department of Agriculture; Uttar Banga Krishi Viswavidyalaya, North Bengal University of Agriculture; research stations; and NGOs are independently funded and function in isolation.

Bihar (Madhubani and Purnea districts)

Bihar, India, is characterised by an entrenched, feudal agrarian structure with a history of political disruption and a breakdown of law and order. Rural development became possible again in 2006 when a pro-development government introduced a range of new initiatives. Bihar's institutional landscape is characterised by strong women and poor-centric NGOs who have established extensive social infrastructure in the form of self-help groups. The NGO JEEViKA, an SRFSI partner organisation, is well connected to all other actors, but there is little interaction or coordination of effort between organisations and no joint activities.

Purnea has better irrigation and marketing infrastructure than Madhubani, and significantly more cash cropping (e.g. maize and banana) because of the Kosi surface-water irrigation scheme and large agricultural markets. Extension services are few, have limited budgets and staff, and offer little mechanisation expertise. Most of Madhubani's farmers are tenant sharecroppers without access to capital or resources. Despite being prone to flooding, only 30% of the district is irrigated.

Terai of Nepal (Sunsari and Dhanusha districts)

Sunsari enjoys a better enabling environment for CASI uptake than Dhanusha, which is more remote from services, has less sanitation and irrigation infrastructure, and poor roads. Sunsari contains the Koshi River surface-water irrigation infrastructure, a wide range of public organisations involved in agriculture and a strong urban market pull. Coordination of agricultural actors within and between the public, private and civic sectors is worse in Dhanusha than in Sunsari. There is little coordination between public and private sector agricultural actors. There has been rapid growth of private sector agrovets who are the main source of inputs for farmers. However, given the open border with India and lack of regulatory oversight of input quality, the supply of quality seed is problematic. There are few Department of Agriculture technical officers and extension is limited. The Department of Agriculture's training centres for technicians and lead farmers are a potential way to introduce SRFSI technologies.

Male labour out-migration and the feminisation of agriculture

The term 'feminisation of agriculture' refers to the increase in the amount of farm work performed by women whether as independent producers, unpaid workers or agricultural wage workers (Lastarria-Cornhiel 2006). Although male labour migration is a longstanding response to food insecurity across the EGP, the nature of labour markets available to rural men and women have changed significantly. The traditional food wages afforded by the zamindar–tenant relationship (Joy & Everitt 1976) are no longer the norm. The Mahatma Gandhi National Rural Employment Guarantee Act is a scheme introduced in 2005 providing a welfare net of 100 days unskilled work per year. It has dramatically increased the bargaining power of male and female labourers, through the breakdown of caste barriers and allowing labourers to be more assertive and courageous (Jakimow 2014). Within India, urban labour is more profitable than farm labour, which has left rural areas with a labour shortage that has pushed up rural wages (Erenstein & Thorpe 2011).

Widespread male circular and overseas labour migration inevitably alters gender relations, as the everyday decision-making that farming women are forced to take over incrementally loosens entrenched patriarchal social structures (Darbas et al. 2020). The process is complex, because gender identity intersects with other aspects of identity such as caste, class, marital status and age (Ravera et al. 2016). Gender relations change in an incremental rather than transformational manner, largely because of the prevalence and acceptability of domestic violence, which can be triggered by perceived threats to male status (Lahiri-Dutt 2014). Researchers have found that women protect male and family status by de-emphasising their economic contribution and so avoid working outside the family home and farm (Ramamurthy 2010). In a ‘complex combination of love and fear’, women ‘combine strategic compliance and accommodations with small acts of everyday resistance’ (Rao 2012, p. 1044).

Feminisation of agriculture has not occurred to the same extent equally across the EGP. Feminisation in Nepal and Bangladesh is consistent with expected trends in other developing countries, because women need to fill the roles of male labour in agriculture when men out-migrate (Sen et al. 2019). India-wide, rapid feminisation of the agricultural workforce occurred in the 40 years to 2004–05, when women comprised almost 50% of the labour force (Garikipati 2008). However, a trend of defeminisation seems to be occurring in Indian EGP (Bihar and West Bengal), which could be related to higher levels of unemployment and a lack of jobs. It could also be because women were forced out of work due to extra-domestic work such as collecting water, fuel and fodder (Sen et al. 2019). 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 (Joshi, Joshi & Kishore 2019). In these parts of India, it is possible that increased pay through male migration has meant that women do not need to seek wages (Joshi, Joshi & Kishore 2019). Furthermore, seasonal male migration during peak periods means that there may also be fewer jobs available for women (Sen et al. 2019).

Migration has characterised Nepalese livelihoods for 200 years, but increased from 88,000 people in 1942 to more than 4 million in 2008. In 2008–09, remittances formed 30% of Nepal’s gross domestic product (GDP). Like India, 90% of Nepal’s migrants are male. Unlike India, Nepalese migration is mostly international: approximately 77% to India and 15% to Gulf countries (Gartaula, Visser & Niehof 2012). Similarly, Bangladesh’s north-west region is a major source for 2.8 million predominantly male migrants to Gulf and South-East Asian countries, whose remittances formed 10% of GDP in 2008 (Raihan et al. 2009). In Bihar's money order economy—other than the poorest, the largest landowners and successful businessmen—nearly all others migrate, with 95% of Bihari migrants being male (Deshingkar et al. 2009). Most migrants are absent for 3–9 months. In north Bihar, migration rates increased from 28% to 49% in 17 years, with remittances accounting for approximately one-third of total average annual income in villages (Deshingkar et al. 2009).

An extensive SRFSI scoping study of female household heads was done in Bihar (East Champaran, Madhubani and Purnea) districts, West Bengal (Cooch Behar and Malda districts) and the eastern Terai (Rautahat, Jhapa, Morang, Mahottari and Saptari districts) (Lahiri-Dutt 2014). 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.

Survey respondents expressed a critical need for:

- timely availability of labour during land preparation, transplanting and harvesting
- agricultural extension services and improved inputs
- good-quality, reliable and timely information and training
- better market access and marketing channels.

Initial discussions between researchers and farmers before the start of the SRFSI project to understand socioeconomic constraints for food production systems in Bhagalpur, Bihar, India, 2012. Photo: Peter Brown, CSIRO

Lahiri-Dutt (2014) recommended creating an enabling environment, so that female household heads could take control of livelihood assets, and be included in existing and new institution, such as Krishi Vigyan Kendra, Indian agricultural extension centres; farmers clubs; and water-user committees. EGP women have less control over land and non-land productive assets than men, and land preparation is traditionally done by men. Farm mechanisation is a process of forming rural capital goods, which are likely to alleviate poverty through rural development (Biggs, Justice & Lewis 2011). Women's access to CASI knowledge and machinery is thus central to the SRFSI project.

To encourage responsible scaling, three strategies were used to engage females as cultivators through the SRFSI project (Table 2.4). Strategies 2 and 3 were delivered through the IPs (see Chapter 3) in 40 villages and 8 districts, to improve coordination between farmers and agricultural agencies, and to develop CA business models. Darbas et al. (2020) concluded that resource-poor female farmers need to be empowered to grasp the opportunity agricultural mechanisation, CA and intensification offer to be a stakeholder in the EGP's rural development. This requires continuous assistance for women; collectivisation to gain bargaining power; and access to institutional credit, machinery subsidies and training.

Table 2.4 Progress made towards engaging females as cultivators through the SRFSI project

Strategy	Progress
1. Promoting gender mainstreaming of extension services with 30% quota for female participants	• Mainstreaming women as individuals without the mutual support and protection afforded by women's groups or negotiating male consent for new freedoms, which limits women's involvement in CASI. • Mainstreaming is a slow mechanism to rely on in a limited-time intervention, and is limited because it is only a small window into an already entrenched and increasingly maladaptive pathway.
2. Development of female entrepreneurs as part of improving value chains	• Developing roles for community business facilitators that were compatible with traditional gender role divisions, and are extra non-agriculture, household-based livelihood activities.
3. Partnering with NGOs proficient in socioeconomic mobilisation of resource-poor women in rural areas.	• Combining nonprofit sector expertise in social mobilisation and marketing with the technical backstopping provided by public sector agricultural organisations enabled traction to be gained in profitable input and output markets. • Increasing collective action by smallholders of either gender is necessary to increase their bargaining power.

CASI = conservation agriculture–based sustainable intensification; NGO = non-government organisation
Darbas et al. (2020)

3 Innovation platforms: private sector engagement and business models

The Sustainable and Resilient Farming System Intensification (SRFSI) project established innovation platforms (IPs) to facilitate adoption of conservation agriculture–based sustainable intensification (CASI) technologies by the millions of smallholder households in the Eastern Gangetic Plains (EGP) (Brown & Darbas 2016). The limited number of public sector extensionists or traditional extension programs cannot reach the large number of smallholders and sharecroppers, often women left behind as a result of male labour migration. IPs are seen as a way to leverage public extension by coordinating with the extensionist, and civic and private organisation programs that are mandated to improve rural livelihoods by commercialising smallholder farming.

IPs are multistakeholder forums that aim to achieve institutional change—in this case, facilitate mass CASI adoption—by nudging the relevant stakeholders and organisations into coordinated action at multiple levels to address a problem. IPs were initially developed at the community (node) level in SRFSI study sites to gather the different priorities that represented the geographically different EGP communities and farming systems. The local IPs were then linked to higher levels of decision-making and resourcing of sustainable intensification of agricultural production through district-level IPs.

IPs have proven to be successful for linking private, civil and public sector stakeholders to collectively identify and work towards overcoming barriers to improving agricultural productivity. Some of the problems discussed and collaboratively addressed—at least partially—through IPs include the availability of:

- quality fertilisers, herbicides and seeds at the right time
- machinery and lack of skills for repair and maintenance
- technical knowledge and skills about crop management practices.

IPs have also facilitated integration of food production with energy and water management considerations at a local level. This level is interested in the practical solutions offered by SRFSI to overcome labour, energy and water shortages.

In the following sections, we summarise the SRFSI activities that were done to support IPs. Further evaluation and synthesis of the IPs is ongoing, and will be published in a peer-reviewed article.

Nepal private sector engagement and business models

IPs have been established at the node and district levels in Dhanusha and Sunsari districts. Stakeholders involved with the IPs are:

- line agencies—District Agriculture Development Office, agricultural research stations, National Seed Company, Agriculture Inputs Corporation, Agricultural Development Bank
- service providers—machinery dealers and suppliers, seed dealers and agrovets, irrigation and market management committees, and tractor owners and operators
- women's self-help groups, farmer groups, lead farmers, cooperatives and community business facilitators.

IP meetings have allowed participants to share knowledge, understand problems and reach out to related agencies for solutions. The major issues raised by the farmers in the nodes are the poor availability of:

- inputs such as quality seed, fertilisers and herbicides
- services such as irrigation, mechanisation and marketing of the agricultural products, including technical knowledge and skills for improving agricultural production.

Each district in Nepal has a District Agriculture Development Office. This is the key extension agency that subsidises and trains farmer groups—but only those registered with the office. IPs in both districts remain notional and do not meet regularly (Tables 3.1 and 3.2). Institutionalising the methodology is considered to be a policy issue that needs continuous effort to develop functional networks and capacities, to bring it into the mainstream. Consequently, more investment is expected to achieve sustainable operation, particularly for the field technicians.

International Development Enterprises (iDE)—a Nepalese non-government organisation (NGO)—introduced community business facilitators to strengthen links with service providers by creating demand for services in return for a commission. Through SRFSI, 14 male and 4 female community business facilitators were trained, but only two have been effective. Essentially, only two IPs are functioning as intended: Kaptanganj in Sunsari and Sinurjoda in Dhanusha (Darbas 2017).

Demonstration of a rice transplanter at an information exchange event as part of the SRFSI project, Cooch Behar, West Bengal, 2018. Some 300 farmers (both men and women) attended the event. Photo: Peter Brown, CSIRO

Table 3.1 Progress in Sunsari district, 2017

Node	Interviewed	ZT scaling	IP	Access to benefits from participating	Marketing
Bhokraha	FT/FGL, woman FG leaderw	• 15 ha ZT maize • 25 ha ZT wheat	Formed August 2016, no meetings since	• Yes—STW and wheat seed subsidy • No—granary	• Hybrid vegetable seed to CGNS Seeds • Wheat seeds to CGSN and India (across border) • Wheat at farm gate
Salbani	FT, 2 male farmers	• No	Formed August 2016, no meetings since	• No—irrigation and wheat seed subsidy (grow maize) • Prefer smaller, simpler, cheaper machinery	• Vegetables
Kaptanganj	FT, 8 male farmers	• 3 ha ZT maize • 60 ha ZT wheat (across 2 villages) • DSR in 1 ha • LLL 20 ha and 12 farmers • Higher ZT wheat yield with same variety	3 IP meetings held, including in the neighbouring Devangung village	• Yes—wheat seed subsidy, to receive 50% subsidy for ZT machine and organic fertiliser • No—cold storage	• Wheat and wheat seed in India (across the border) • Vegetables
Simariya	FT, male farmers	• 5 ha ZT wheat • ZT lentil failed (calibration, weed infestation)	IP meeting held 3 months ago	• Yes—wheat seed subsidy • No—reliable irrigation schedule, trained driver quit, timely and affordable tractor, LLL	• Wheat at farm gate
Bhaluwa	Woman FT/ FG leader	• 6 ha ZT wheat • 0.5 ha ZT maize	IP meeting held 3 months ago	• Yes—wheat seed subsidy, to receive phone and IT advisory services • No—timely irrigation, timely and affordable tractor, driver training	• Grain at farm gate (procurement via cooperative collapsed)

DSR = direct-seeded rice; FG = Farmers Group; FGL = farmers group leader (leader of Famers Group); FT = field technician (a farmer employed to help implement the SRFSI project); IP = innovation platform; LLL = laser land leveller; STW = shallow tube well; ZT = zero-till

Table 3.2 Progress in Dhanusha district, 2017

Node	Interviewed	ZT scaling	IP	Access to benefits from participating	Marketing
Raghunathpur	FT/ FG leader, 4 male farmers, secretary of women's FG, 6 women farmers	• 2 ha ZT wheat and 6 farmers • 4 new ZT wheat farmers from neighbouring village	IP meeting was last held 8 months ago	• No—STW or reliable canal irrigation, wheat seed subsidies	• Sell grain at farm gate
Gidha	FT, tractor owner/ operator, 8 male farmers	• 2 ha ZT wheat and 9 farmers • 2 farmers from neighbouring villages • 15 and 10 katthas of ZT wheat • DADO provided seed and herbicide for outscaling to 41 ha of land	IP meeting was last held 8 months ago	• Yes—wheat seed subsidy • No—seed, fertiliser, MSP, timely and affordable tractor and reaper	• Sell grain at farm gate • Vegetables
Phulgama	FT, women's SHG/ FG leader, 2 female farmers, 9 male farmers	• 1.5 ha ZT wheat and 10 farmers, including 5 women • 0.5 ha ZT lentil and 5 farmers, including 2 women • ZT wheat grain larger and plant more vigorous than conventional	IP meeting was last held 8 months ago	• Yes—STW • No—timely and affordable tractor, trained Nepalese drivers, subsidy for power tillers	• Sell grain at farm gate • Vegetables
Sinurjoda	FT, the women's FG leader, 5 female farmers, 2 male farmers	• 9 ha ZT wheat and 35 farmers • 2 kattha ZT mung and 1 farmer • Planning 10 ha ZT mung this season under the Prime Minister Agriculture Modernization Project • A small area of ZT forage	IP meeting was last held 8 months ago	• No—timely and affordable tractor, harvester and thresher machine (even a cheap pedal thresher)	• Selling wheat seed • Forage seed to district livestock officer, visiting farmers, sold 120 quintal for Rs1,200,000 to Teosinte
Lalgadh & Bengadabhar	FT, 11 women farmers, 11 male farmers	• Wheat crop failed (subsoil constraint)	IP meeting was last held 8 months ago	• No—reliable irrigation, seed	• Sell grain at farm gate

DADO = District Agriculture Development Office; FG = Farmers Group; FT = field technician (a farmer employed to assist with the implementation of the SRFSI project); IP = Innovation Platform; MSP = minimum support price; Rs = Nepalese rupee; SHG = self-help group; STW = shallow tube well; ZT = zero-till

Bangladesh private sector engagement and business models

Small and fragmented plots of land characterise agriculture in northern Bangladesh. Small and marginal farmers do not have the capacity to invest in improved crop cultivation. Many private companies are involved in agricultural input supply (i.e. seed, fertiliser and pesticides) and some private companies also purchase produce. However, they largely depend on intermediaries (dealers, retailers, purchasers, etc.). Few banks and financial organisations provide institutional credit and it is difficult for smallholders to access. Government service provision is insufficient to cover all services in all areas under their jurisdiction. Consequently, farmers use local markets to purchase inputs and sell produce. Intermediaries play a vital role in providing advice and inputs regardless of their expertise or level of knowledge. Thus, atypical or uncommon problems tend to attract incorrect advice. Smallholder farmers in Rangpur and Dinajpur are poorly coordinated with public sector and private sector support-service providers. Through IPs, the SRFSI project is helping the private sector to contribute to increasing the productivity, profitability and sustainability of smallholder agriculture. The IPs aim to help the private sector change the way they do business, so that their activities benefit both the poor and their businesses.

Rajshahi private sector engagement and business models

The Wheat Research Centre and On-Farm Research Division of the Bangladesh Agricultural Research Institute are implementing the SRFSI project in Rajshahi district. The five village nodes cover three distinct agroecosystems: the high Barind Tract (Laxmipur, Premtoli and Nabinagar), charland (Baduria) and plains (Dharampur).

Each node has IPs that have met several times and are actively addressing production issues. All IPs aim to increase coordination between the multiple agencies distributed across the public, private and civic sectors working towards agricultural development. IP stakeholders include:

- farmers and Integrated Catchment Management Farmer Club members
- Department of Agricultural Extension personnel
- Bangladesh Agriculture Research Institute and Barind Multipurpose Development Agency officials
- private and public input dealers
- Rajshahi Krishi Unnayan Bank
- NGO representatives
- local cooperatives
- SRFSI field technicians
- Rural Electrification Board member
- milk-processing unit member
- local agromachinery service provider
- deep tube well operator.

The Rajshahi nodal level IPs are also focal points for developing CASI equipment hire hubs—a SRFSI business model for ensuring that resource-poor farming households have affordable access to expensive equipment (Table 3.3). The SRFSI project has trained service providers who can maintain and operate these machines. Box 3.1 describes some of the CASI equipment available.

Table 3.3 Rajshahi Innovation Platform machinery and contract services, 2017

Node	Machinery services
Laxmipur	Two- and four-wheeled tractors, thresher and deep tube wells are available to farmers on a custom hire basis. Strip tillage machines, bed planters, rice transplanters and laser levellers are available to the SRFSI farmers group, and farmers are paying for this service.
Nabinagar	Two- and four-wheeled tractors, deep tube wells and threshers are available to local farmers on a custom hire basis. Strip tillage machines, bed planters and rice transplanters are available to the SRFSI farmers group.
Premtoli	Two- and four-wheeled tractors, deep tube wells and threshers are available to local farmers on a custom hire basis. Strip tillage machines, bed planters, rice transplanters and laser levellers are available to the SRFSI farmers group. Strip tillage machine and bed planter services are available to farmers.
Baduria	Two- and four-wheeled tractors, shallow tube wells and threshers are available to local farmers on a custom hire basis. Strip tillage machines, bed planters, rice transplanters and laser levellers are available to the SRFSI farmers group. Strip tillage machine and bed planter services are also available to farmers because well-trained service providers are available.
Dharampur	Two- and four-wheeled tractors, deep tube wells, shallow tube wells and threshers are available to local farmers on a custom hire basis. Strip tillage machine, bed planters, rice transplanters and laser levellers are available to the SRFSI farmers group. Strip tillage machine and bed planter services are available to farmers because well-trained service providers are available.

SRFSI = Sustainable and Resilient Farming System Intensification

Box 3.1 Conservation agriculture–based and sustainable intensification equipment

The Bangladesh Agriculture Research Institute (BARI) has developed a good zero-till machine that sows most grain seed crops in line in a single pass. However, farmers are reluctant to adopt it.

The strip tillage machine is unique to Bangladesh, as it and its spare parts are manufactured locally. All SRFSI nodes have one, BARI and the International Maize and Wheat Improvement Center are promoting it, the operators who walk behind it are accepting it and demand is increasing. Multiple crops can be sown in line in a single pass.

BARI has improved its seed metering system (inclined plate) to enhance accuracy and efficiency.

The bed planter machine tills, prepares the bed and seeds in a single pass, and is popular in Rajshahi because wheat yields after bed planting have increased significantly, while irrigation and weeding costs have decreased.

The thresher has been successful in Bangladesh. All the districts have local manufacturers, and competition among them has driven down prices. It is used for paddy, wheat, maize and pulse crops, and is cheaper than traditional threshing. Service providers can move their threshers easily and cover a large service area (open drum threshers can be carried, and heavier threshers have wheels).

Reapers are gaining popularity, and are used for rice and wheat. They also lay plants for drying.

The Premtoli node is in both the Barind and plain land environment. It has high temperatures and low rainfall. The soil pH is low in the Barind and slightly high in the plains. Many crops, including cereals, pulses, vegetables and fruits, are grown and most households also own cattle. Many stakeholders are jointly or separately working to develop agriculture in this region, but do not coordinate with each other. An IP was formed in late 2015. However, private input suppliers, local government representatives, Rural Electrification Board (REB) personnel and government microcredit organisations have limited their participation in the IP. See Table 3.4 for a summary of IP progress in the Rajshahi nodes. Baduria node is in a charland agroecology area, with light soils with a pH >8. Cereals, pulses, vegetables, sugarcane and fruits (mango, ber and guava) are extensively cultivated here. An IP was formed in early November 2015. Some IP members (private input suppliers, local government representatives, microcredit organisations and REB personnel) have limited their participation in IP meetings. Farmers receive a fair price for their product at a large market 3 km from the node, where many local buyers are. The node has been able to store 700 kg of wheat seed.

Laxmipur node is in the water-scarce Barind region, and has high temperatures, low rainfall and low soil pH. Cereals, pulses and fruits are grown, and many households rear

Table 3.4 Innovation platform progress in the Rajshahi nodes, 2017

Problems	Node	Initiative taken
Limited availability of quality seed	All nodes	Local input dealers and progressive farmers agreed to preserve more quality seeds for farmers. The private seed company and public seed authority were encouraged to supply quality seed on a demand basis in subsequent seasons.
Deep tube well electricity supply	Premtoli Laxmipur	REB was requested to supply uninterrupted electricity to deep tube wells.
Pest management	All nodes	DAE local personnel committed to provide pest and disease control advice.
Microcredit	Baduria Dharampur	Local cooperative society agreed to supply low interest loan to SRFSI farmers.
Deep tube well servicing	Laxmipur Nabinagar	BMDA agreed to provide immediate support to address sudden problems with deep tube wells.
Farmers access to irrigation water	Laxmipur Nabinagar	Provision of irrigation water is the main dry season problem in this drought-prone area; however, the deep tube will operator is committed to providing access.
Service provider's cost	Dharampur	Service providers agreed to service for a reasonable price.

BMDA = Barind Multipurpose Development Agency; DAE = Department of Agricultural Extension; REB = Rural Electrification Board; SRFSI = Sustainable and Resilient Farming System Intensification geese and ducks. An IP was formed in mid 2016. Local government representatives, REB personnel and governmental microcredit organisations had limited involvement in this IP. Government seed authorities in this node include the Bangladesh Agricultural Development Corporation and the Barind Multipurpose Development Agency.

Nabinagar node is also in the water-scarce Barind region, and has high temperatures, low rainfall and low soil pH. Monsoon-season rice is the main crop grown here, and also wheat, pulses, oil seed crops and fruits (mango, guava and ber). Many households have small farms with cattle, sheep, goat, geese and ducks. Many government organisations and NGOs, together or separately, are working to develop agriculture in this region, but overall there is a lack of coordination. An IP was formed in mid 2016 to bring stakeholders under the same umbrella. The limited involvement of the local government representatives, REB personnel and government microcredit organisations has improved. Government seed authorities in this node include the Bangladesh Agricultural Development Corporation and the Barind Multipurpose Development Agency.

Dharampur node is in a plain land environment with a clay-loam soil with a high soil pH (above 8). Cereals, pulses, oil seeds, spices, vegetables and fruit (mango, banana and guava) are extensively cultivated here. The stakeholders are somewhat coordinated to develop agriculture in this node. An IP was formed in mid 2016. Local government representatives, REB personnel and government microcredit organisations have so far limited their participation in IP meetings.

Rangpur–Dinajpur private sector engagement and business models

IPs have been established and a common service model and a business model have been implemented. Private sector businesses and government departments are engaged in all five nodes of Rangpur district. After private businesses became involved, farmers received more profit for their products and more farming services. The public and private sector IP stakeholders include:

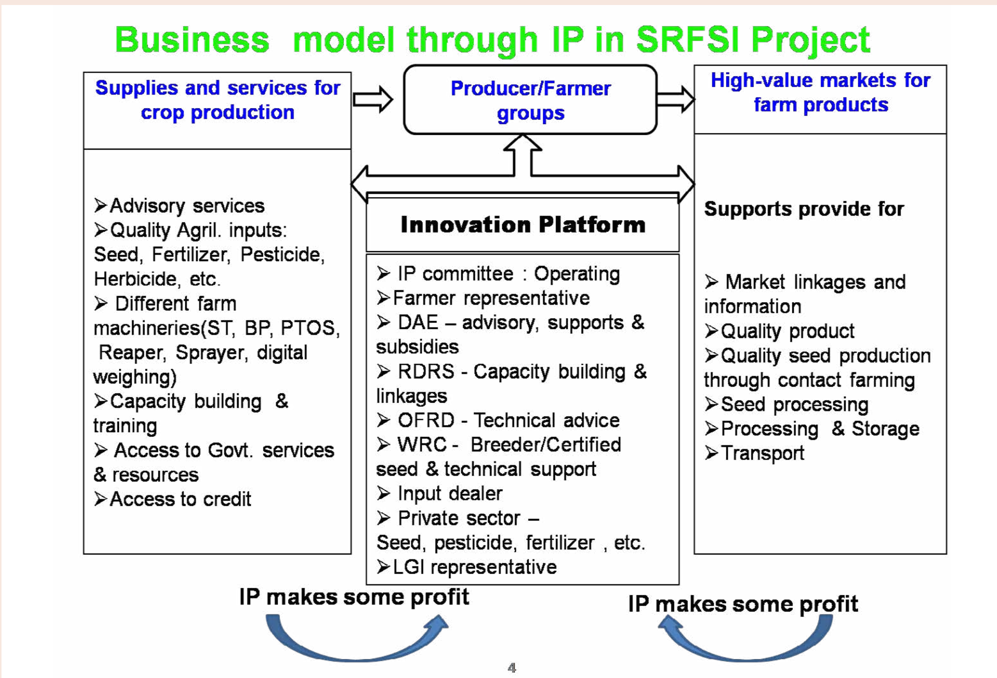
- farm machine manufacturer—Reshma Engineering
- local service providers
- agricultural extension agencies—Department of Agricultural Extension, Department of Livestock Services, Department of Fisheries
- research organisations—On-Farm Research Division, Bangladesh Agriculture Research Institute; Wheat Research Centre; Bangladesh Rice Research Institute
- NGOs—RDRS, World Vision, Caritas, BRAC, iDE and others
- finance organisations—Scheduled Bank, microfinance institutions, Rajshahi Krishi Unnayan Bank
- private companies—Advanced Chemical Industries, Ispahani, Auto Crop Care
- input dealers.

These actors are closely involved with the IPs, but with very clearly defined roles. A common service model has been established to ensure smallholders receive services. The Department of Agricultural Extension, the Department of Livestock Services, the On-Farm Research Division of the Bangladesh Agriculture Research Institute, RDRS and private companies disseminate their modern technologies through the IPs. Private companies arrange awareness sessions, and train farmers to use improved products and technologies.

The IP creates an opportunity for companies to demonstrate their products and services to farmers for the benefit of both parties. The private sector increases their competitive advantage, accesses new market opportunities and can engage in value-chain upgrading due to a more enabling environment for their businesses (Figure 3.1). An agricultural community clinic and information centre has been established at each node where companies display their quality seeds and pesticide samples. Farmers now consider the IPs to be one-stop service shops (Figure 3.1).

The IP's role in achieving this business service model is fourfold, and provides:

- facilitation, to bring local actors together to undertake the activities, build relationships, fill in knowledge gaps and facilitate the actions of the permanent local actors
- technical support to the producers with the assistance of the government and NGOs. This includes providing technical knowledge, business planning and market mentoring
- funding, as the IP provides funds to cover business activities in some cases
- investments, as the IP provides capital to a business in some cases.



BP = bed planter; DAE = Department of Agricultural Extension; IP = innovation platform; LGI = local government institutions; OFRD = On-Farm Research Division; PTOS = power tiller operated seeder; RDRS =non-government organisation; SRFSI = Sustainable and Resilient Farming Systems Intensification; ST = strip tiller; WRC = Wheat Research Centre

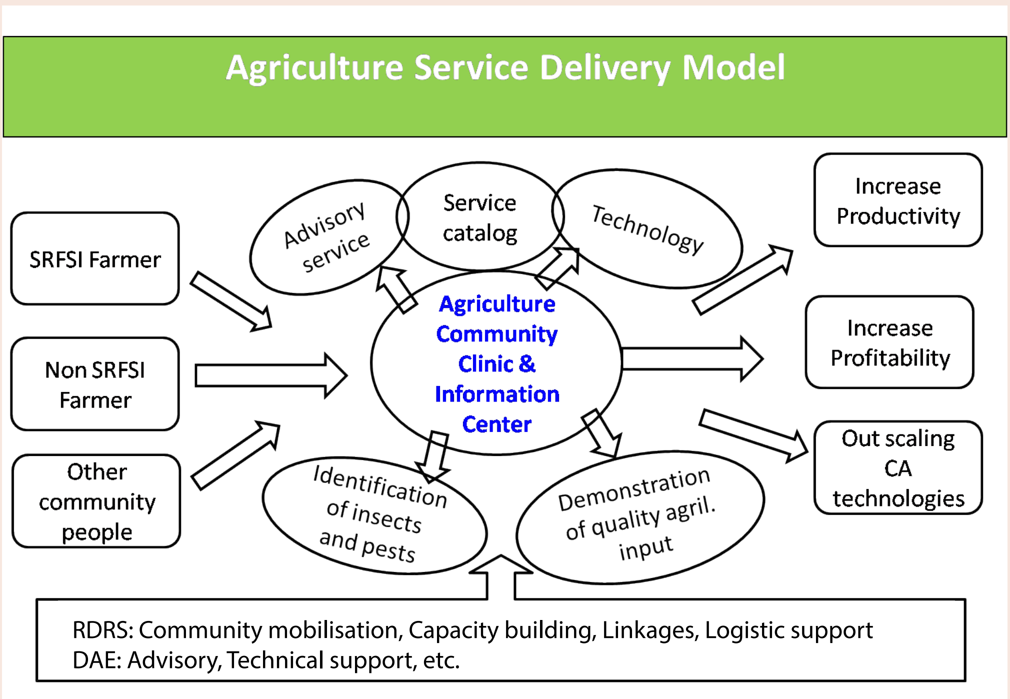
Figure 3.1 Rangpur Innovation Platform business model based on private sector engagement, 2017

This model has coordinated the public agencies and private sector business, and these actors are working together very well (Figure 3.2). This model is working so successfully that there are plans to disseminate it to other areas, although some aspects may need to be modified. It also depends on local demand.

Daskin Kolkondo node IP is a newly formed node-level IP in Gangachara Upazila, Rangpur district. In 2017, 35 general members were depositing savings as collective seed money for starting a business. They rented out their machine, which helped to scale CASI technologies. As at 2017, they had collected Tk9,000 by providing various services to 301 farmers, including advisory services for pest and disease control in various crops, seed distribution and awareness sessions.

Lakkhitari node IP is a node-level IP in Gangachara Upazila, Rangpur district, formed in 2017. Thirty general members were depositing savings as collective seed money for starting a business. They rented out their machine, which helped to scale CASI technologies. As of 2017, they have collected Tk8,000 by providing different services to 370 farmers, including building linkages with seed companies and government departments to purchase quality seed at a subsidised rate, advisory services for pest and disease control in various crops, seed distribution and awareness sessions.

Chitli Rampura node IP, in Durgapur, Rangpur district, was reformed from the former Integrated Agricultural Productivity Project farmers' group established by the Department of Agricultural Extension in Mithapukur Upazila. In 2017, 30 general members were depositing savings as



CA = conservation agriculture; DAE = Department of Agricultural Extension; SRFSI = Sustainable and Resilient Farming Systems Intensification

Figure 3.2 Rangpur Innovation Platform agricultural service delivery model, 2017 collective seed money to establish a business. They rented out their machine, which helped to scale CASI technologies and earned the IP Tk4,300. They have collected Tk8,000 to add to their previous savings of Tk5,000. The IP members have the capacity to collect Tk59,300 in business capital. They have provided services to 354 farmers, including building linkages with seed companies and government departments to purchase quality seed at a subsidised rate, advisory services for pest and disease control in various crops, seed distribution and awareness sessions.

Borodargha node IP was formed within Pirganj Upazila, Rangpur district in 2017. Members have disseminated CASI technologies to 618 farmers. These services included purchasing seed and herbicide from private companies and selling them at minimal profit, renting their zero-till machine for scaling conservation agriculture (CA), and advisory services for pest and disease control in various crops. They have earned Tk19,400 towards establishing a business.

Mohonpur node IP, in Birganj Upazila, Dinajpur district, was reformed from an RDRS Farmer Field School group. They had 30 general members who collected Tk10,630 by providing services to 1,204 farmers, including distributing potato, maize and wheat seed, advisory services for pest and disease control in various crops, awareness and training sessions, and demonstrating CASI technologies.

Details of the five nodes are summarised in Table 3.5.

West Bengal private sector engagement and business models

Uttar Banga Krishi Viswavidyalaya, West Bengal University of Agriculture (UBKV) facilitated all the IPs in West Bengal. Like Bangladesh, the enabling environment for promoting CASI technologies is good, and UBKV and its Krishi Vigyan Kendra extension service has long promoted CASI, which has served as a strong entry point for the SRFSI project. The National Bank for Agriculture and Rural Development (NABARD) has been central in the establishment of farmers clubs. These clubs can become registered organisations and provide collateral assets, which provides institutional credit. During 2016, IPs were established in two districts, but regular

Table 3.5 Rangpur–Dinajpur node IP progress, 2017

Node	IP status	Members (no.)	Savings (Bangladeshi taka)	Outreach via service provision (no.)
Daskin Kolkondo	Newly formed	35	9,000	301
Lakkhitari	Newly formed	30	8,000	370
Chitli Rampura	Reformed DAE IAPP group	30	13,000	354
Borodargha	Newly formed	40	19,400	618
Mohonpur	Reformed RDRS FFS group	30	10,630	1,204

DAE = Department of Agricultural Extension; FFS = Farmer Field School; IAPP = Integrated Agricultural Productivity Project meetings and discussion were needed to strengthen the collaboration. In 2016, the links were forged with multinational agro-input companies Essar Oil, Monsanto and Godrej Agrovet. The companies provided a laser land leveller in Malda district and increased farmer capacity by distributing high-yielding varieties in Cooch Behar district.

Cooch Behar district private sector engagement and business models

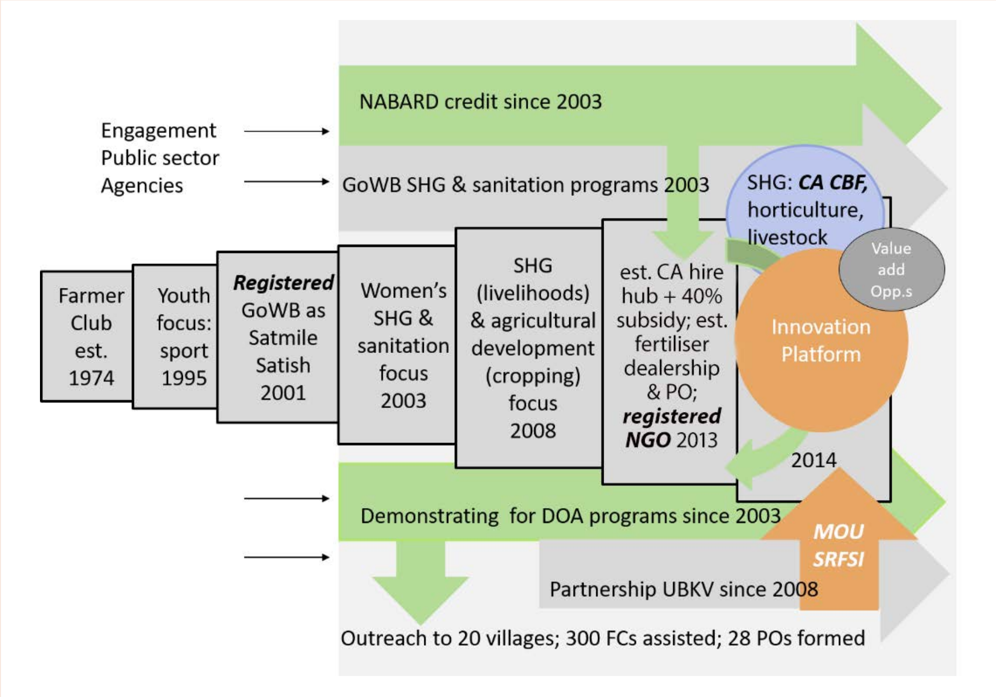
The five node-level IPs in Cooch Behar district were established in 2016, and each node held three to four IP meetings. Meetings focused on awareness-raising and sensitisation of the IP members regarding their roles and functions, continuation of SRFSI project deliverables (e.g. on-farm trials, field days), identifying new production issues requiring resolution and preparing strategies to solve them. All IPs include:

- public sector actors such as the Department of Agricultural Extension and relevant line departments (e.g. horticulture and livestock)
- private sector input supply actors (e.g. seed, fertiliser, CASI machinery)
- voluntary organisations such as local NGOs and farmers clubs.

SRFSI activities have been integrated with those of the state Department of Agriculture flagship programs: Bringing the Green Revolution to Eastern India and National Food Security Mission on Pulse. This has increased outreach to farmers, both inside and outside the project, through supply of high-yielding varieties and CA technology. SRFSI activities have also been integrated with Krishi Vigyan Kendra clusters to demonstrate zero-till maize and wheat, which has increased the area and productivity of those crops, thus affording economic and social benefits to farmers in these areas.

Figure 3.3 shows that the IP run by Satmile Satish Farmers Club, formed in 1974, has benefited from engaging with NABARD and government departments since 2003, with UBKV since 2008 and with SRFSI since 2014. The club has established a CA hire hub using a 40% NABARD subsidy to purchase tractors and attachments, and also offers women community business facilitators an income stream for promoting CASI services to households. In 2017, the club's outreach to villages and farmer clubs has resulted in the formation of two producer organisations seeking to establish themselves as profitable businesses.

Sabuj Mitra Farmers Club at Durganagar node (Figure 3.4) has been transformed into a profit-making producer organisation by adopting the IP method and forging a strong link with NABARD. A custom hiring centre for farm implements has been established with NABARD credit. The cost of driver and helper for zero-till wheat, lentil, mustard, mung, jute and rice was ₹3,000/ha, and for zero-till maize the cost was ₹3,750/ha. This IP has developed a business model to introduce maize cropping. As maize is a new and unfamiliar crop in Cooch Behar district, the IP has developed a contract system whereby the farmers club is responsible for the package for the first 50 days. This package includes crop zero-till sowing, quality hybrid seed, fertiliser, herbicides, irrigation and pest control. After 50 days, the crop becomes the farmer's responsibility. The club charges ₹3,000/1,330 m^2 or ₹22,222/ha. The club obtains hybrid seed, fertiliser, herbicides and pesticides at a discounted rate directly from Essar Oil, Monsanto and Godrej Agrovet. This model creates a cluster of maize farmers rather than individual farmers working in isolation. Both parties benefit while reducing risk. The club intends to establish an input dealership to further develop its income streams. The income provides a salary for six farmer club members who are actively involved in these programs.



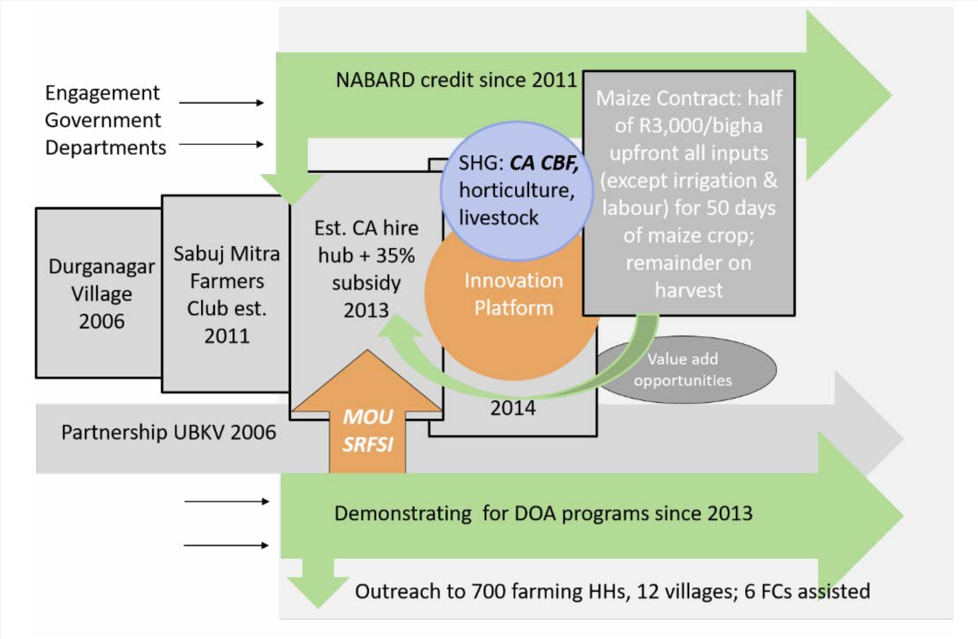
CA = conservation agriculture; CBF = community business facilitator; DOA = Department of Agriculture; FC = farmer clubs; GoWB = Government of West Bengal; MOU = memorandum of understanding; NABARD = National Bank for Agriculture and Rural Development; PO = producer organisations; SHG = self-help group; SRFSI = Sustainable and Resilient Farming Systems Intensification; UBKV = Uttar Banga Krishi Viswavidyalaya, West Bengal University of Agriculture

Figure 3.3 Satmile Satish Farmers Club Innovation Platform, Cooch Behar district, 2017

Malda district private sector engagement and business models

The Gazole area of Malda district is dominated by a rice–lentil cropping system using local varieties of lentils. In 2013, the Farmers Club Vivekananda Krishak Sangha, in Kalinagar node, introduced two improved lentil varieties (Subrato and Maitree) using zero-till drilling and broadcasting. As the crops were successful, the whole village (comprising approximately 150 ha) adopted zero-till and surface seeding of lentil in the 2015–16 cropping season. This practice is now being used in neighbouring villages. The club has also registered as a producer organisation, and established an implement hub and custom hiring centre by borrowing money from NABARD. In 2017, the charge for sowing, including a driver and assistant for zero-till wheat, lentil, mustard, mung, jute and rice was ₹3,000/ha and for zero-till maize the cost was ₹3,750/ha.

The Manikchak Progressive Farmers Club in Malda started producing high-quality wheat seed varieties in 2014–15. In 2016, 57 farmers (including four women) registered under a seed production program. The wheat was sown using CASI principles and practices to produce both foundation and certified seeds. Seventeen fields were rejected due to infestation by the weed *Phalaris minor*. Samples from 25 farmers were rejected due to high moisture content and low germination rates, leaving the high-quality seeds of 15 farmers. A total of 78.31 quintal of wheat seeds of various grades were



CA = conservation agriculture; CBF = community business facilitator; DOA = Department of Agriculture; FC = farmer clubs; HH = households; MOU = memorandum of understanding; NABARD = National Bank for Agriculture and Rural Development; SHG = self-help group; UBKV = Uttar Banga Krishi Viswavidyalaya, West Bengal University of Agriculture

Figure 3.4 Sabuj Mitra Farmers Club Innovation Platform, Cooch Behar district, 2017

certified through this participatory seed production. The growers earned ₹700/kg for certified seeds (a 61.5% price increase) and ₹1,500/kg for foundation seeds (a 115.4% price increase). This result motivated the club to apply to NABARD to form a seed producer's organisation. The club began lentil seed production in 2015–16 on 20.14 ha—71.7 % more land than was used for this purpose the previous year.

Bihar private sector engagement and business models

SRFSI implementation was led by Bihar Agriculture University in Purnea district and by the Indian Council for Agricultural Research in Madhubani district. Purnea and Madhubani districts had different enabling environments.

Purnea benefited from a large maize market and was a leading maize production district. The district also benefited from strong donor flows supporting multiple rural livelihood NGOs. The World Bank–funded JEEViKA NGO (or Bihar Rural Livelihoods Project) has been working in Purnea district since 2009 and building the capacity of resource-poor farming women though self-help groups and village resource persons.

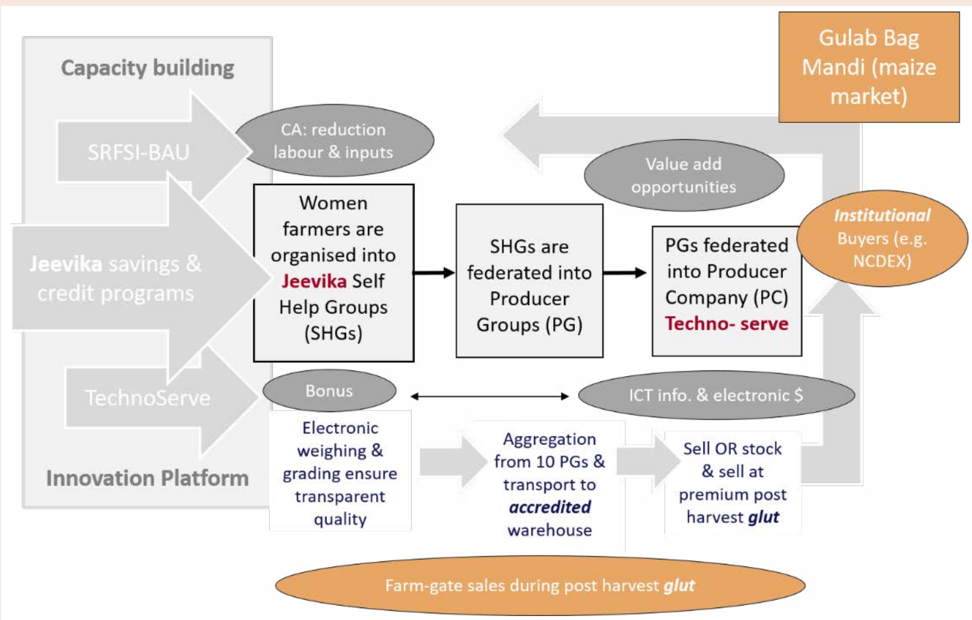
JEEViKA's involvement in Madhubani district was more recent, and fewer women's self-help groups have formed producer groups or 'graduated' from four levels of group training (awareness, motivation, modus operandi and execution). Madhubani district's more feudal socioeconomic structures make the number of tenant farmers higher and access to irrigation lower than in Purnea.

Purnea district private sector engagement and business models

All five nodes have established an IP for scaling-up CASI technologies and solving farming problems. Private sector engagement and a business model is most advanced in Purani Garel node, and is the only SRFSI IP working exclusively with women producers (see Figure 3.5). This outcome is a result of a partnership between Bihar Agricultural University, JEEViKA and the NGO TechnoServe (funded by the Bill & Melinda Gates Foundation). TechnoServe was responsible for undertaking a market survey in all nodes, which found that farmers were not receiving timely or remunerative prices for their maize due to the dominance of vendors in input supply and marketing of produce. Farmers were also uninformed about the market price for maize (Table 3.6).

After 27 producer groups were formed, they formed the Aranyak Agri Producer Company, comprising 2,700 members.

As a response to the vendor malpractice of underweighing grain of up to 6 kg per quintal, the company invested in an electronic weighing machine. To achieve a better grade (and price) for maize, they bought a moisture meter. All transactions are cashless; each producer group member has a bank account. Mobile SMS messaging of market news has been established and prices are also displayed by the village resource person. The company procures maize from the producer groups and stores it in accredited warehouses as per the standard of India's National Commodity and Derivatives Exchange Ltd (NCDEX). The grain is sold when the price is high (after the post-harvest glut) to the NCDEX and/or the large maize market (Gulab Bagh Mandi). Remaining profits are paid as bonuses to the company members. A total of 1,013.9 megatonnes of maize grain was procured in the 2015 Rabi season and a total of 300.3 megatonnes in 2016.



CA = conservation agriculture

Figure 3.5 Purani Garel node business model, 2017

Aranyak has recently signed a memorandum of understanding with the Indian Farmers Fertiliser Cooperative, and received a licence for selling seeds, fertilisers, insecticides, pesticides and herbicides. Aranyak is also constructing concrete floors for drying grain to replace the current practice of drying grains on roads. The company also promotes members as master trainers for the mobilisation of new producer groups. This business model has meant that local vendors also purchased electronic weighing machines, although they also increased their rates for loading and unloading grain at the warehouses.

A second business model was being established in 2017 in the remaining four nodes of Purnea district, through an ACIAR contract with Business for Development (Business for Development 2017). The trial agribusiness model involves establishing and evaluating farmer service companies through micro-entrepreneur centres in the Purnea nodes to outsource access to machinery, inputs and knowledge for farmers. FarmsnFarmers Foundation (FnF) was formed in 2010 and Green Agrevolution Pvt. Ltd in 2012. A joint initiative with Green Agrevolution Pvt. Ltd created the DeHaat concept, to provide 'last mile delivery of 360-degree agriservices' to farmers. Multiple forums have recognised DeHaat, which has received funding from NABARD under the Rural Innovation Fund. DeHaat's aim is to develop village entrepreneurs who can provide a one-stop shop to connect small farmers to their various needs—seeds, fertilisers, machinery, equipment, crop advice and market linkages—through a network of micro-entrepreneurs recruited at the village level.

Table 3.6 Status of Purnea innovation platforms, in terms of private sector engagement and business model steps, 2017

Private sector engagement and business model steps	Innovation platform				
	Purani Garel	Dogachhi	Kathaili	Tikapatti	Udainagar
Primary survey and problems identifed	Yes	No	Yes	Yes	Yes
Market survey completed	Yes	No	Yes	Yes	Yes
Interaction with input dealers and service providers	Yes	Yes	Yes	Yes	Yes
Awareness training about agro-producer company	Yes	No	Yes	No	Yes
Producer groups have been formed	Yes	No	Yes	No	Yes
DeHaat Village entrepreneur selected	Yes	Yes	Yes	Yes	Yes
Producer company formed	Yes	No	No	No	No
Procurement system established	Yes	No	No	No	No

4 Gender

The Sustainable and Resilient Farming Systems Intensification (SRFSI) project has used two strategies to engage women as grain growers, following the broad principles of Kadel et al. (2017):

1. mainstreaming (project) extension services for farming women with a 30% quota for women participants in all project activities
2. establishing multistakeholder innovation platforms (IPs) to improve coordination between farmers and agricultural agencies, and to develop conservation agriculture business models.

The gender mainstreaming strategies in SRFSI are that:

- all project activities are to include men and women
- there is increased gender awareness and appreciation of the importance of incorporating gender aspects in all components of the project
- all districts now use protocols for gender activity reporting and templates
- teams are monitoring participation of men and women in all activities.

There has been an increase in gender awareness and an appreciation of the importance of incorporating gender aspects in all components of the project and all disciplines (socioeconomists, agronomists and biophysical scientists), as evidenced in discussions and the adoption of the gender protocols within the project. Using gender protocols and data-gathering tools are now standard practice in all project activities, to monitor men's and women's participation in various project activities. This strategy helped to overcome the biases that result in women's exclusion by increasing awareness of women as cultivators. The average participation rate of women in SRFSI activities was 33%, with the highest participation in Nepal and the lowest in Bangladesh (37% and 31%, respectively).

Although mobility restrictions on women are strongest in Bangladesh, it is evident across all sites that women's participation in activities within the village (field trials—53%, focus group discussions—40% and farmer field days—38%) is higher than activities out of the village (training workshops—21% and exposure visits—22%).

It should be noted that no incidents of domestic violence against women participating in the SRFSI project have been reported and that overtly challenging mobility restrictions on women may well result in increased violence against them. The community business facilitator strategy remains unproven as a way for women to become empowered economically and requires gender-disaggregated income data to be collected. However, the strategy does have the advantage of women not needing to travel out of the village.

Through post-season focus group discussions, women identified the key positive impacts of conservation agriculture–based sustainable intensification (CASI) as:

- higher incomes
- reduced farm labour use and labour costs
- reduced production costs
- reduced the drudgery of their work
- more time to do other productive tasks
- more leisure time
- better education for their children
- better nutrition for their family.

Men identified the key positive impacts of CASI as:

- higher incomes
- reduced farm labour use and labour costs
- reduced production costs
- increased farm yield
- better education for their children
- better livelihoods for their family.

The clearest, measurable impact of the IPs on women has been in Purnea through the collaboration with JEEViKA. This only works with women through the already-familiar self-help group method evident throughout the Eastern Gangetic Plains. In 2017, this innovation delivered improved incomes to 2,700 women organised into producer groups and a producer company (see Chapter 3, 'Purnea district private sector engagement and business models'). This affirmative action strategy meets the recommendations made by Lahiri-Dutt (2014) (see Chapter 2, 'Male labour out-migration and the feminisation of agriculture') by providing in-situ training, inputs and market access specifically to women cultivators. This example would seem to indicate that SRFSI could engage with women cultivators who belong to self-help groups in other nodes, in addition to working with male farmer groups and clubs.

5 Economic analysis

With the increase in population and use of food grains for livestock and biofuel, a continuous increase in demand of food grain can be expected. However, it is unlikely that this demand will be satisfied by area expansion, as land is scare and also increasingly in demand for non-agriculture use (Rosegrant & Cline 2003). Furthermore, the aberration in climate is making agriculture vulnerable and agriculture productivity uncertain, leaving people dependent on agriculture more vulnerable. The Eastern Gangetic Plains (EGP) frequently suffers from climatic shocks such as flooding, flash flooding, drought, irregular rainfall, and pest and disease infestation. Moreover, due to less mechanisation and use of resource-intensive practice, cost of cultivation is very high and time-consuming, resulting in compromised yields.

The Sustainable and Resilient Farming Systems Intensification (SRFSI) project in this region is promoting conservation agriculture–based and sustainable intensification (CASI) technologies that help to address some of these issues, and improve the productivity of crops and livelihood of people who depend on agriculture.

In the first section, we will first present the spatial variation of major inputs in SRFSI working districts. In the second section, we will review productivity and profitability for 2014–15 and 2015–16. The early data have been expanded on and submitted to *World Development*. The information below provides a broad picture of the economics of CASI across the SRFSI regions, but is still relevant.

Spatial variation

Spatial variation in terms of the cost of some of the major inputs helps explain the difference in cost of production across the districts and net benefits presented in Tables 5.1–5.3. The numbers are presented in Australian dollars wherever possible, and the exchange rate used is the average from June 2015 to allow comparison and avoid fluctuations in exchange rates.[1] For comparison, we have compiled data on labour charge/day, irrigation charge/hour, machinery hiring charge/hectare and cropping intensity because CASI technology significantly reduces costs. CASI technology is based on the principle of minimum soil disturbances, and mechanisation and irrigation affecting cropping intensity. We have used only the machinery used for land preparation, as CASI helps to minimise land preparation costs significantly.

Cost of production differed across states and countries. However, within the same country, there were differences in some of the input costs (Table 5.1). Daily wages paid to labourer and irrigation cost per hour varied in all the districts where the SRFSI project was present.

1 The exchange rates used are 1 Australian dollar (A$) = 58.66 Bangladeshi taka; A$1 = 50.47 Indian rupee; A$1 = 80.57 Nepalese rupee).

Table 5.1 Variation of major inputs and cropping intensity across SRFSI working districts, 2015–16

	North-west Bangladesh		Bihar, India		West Bengal, India		Terai, Nepal	
Variable	Rangpur	Rajshahi	Madhubai	Purnea	Malda	Cooch Behar	Dhanusha	Sunsari
Labour wage (A$/day)	4.26	5.11	2.97	3.84	3.96	4.95	5.59	4.96
Irrigation cost (A$/h)	1.88	1.70	2.18	2.18	1.98	2.18	1.37	1.37
Cropping intensity (%)	224	202	146	131	194	210	185	183

A$ = Australian dollars
Sources: SRFSI field data. Cropping Intensity: Bangladesh Bureau of Statistics (2016), Indian Department of Agriculture Cooperation and Farmers Welfare (2017), Ministry of Agriculture Development (2013)

Table 5.2 Variation of major inputs for rice across SRFSI working districts, 2015–16

	North-west Bangladesh		Bihar, India		West Bengal, India		Terai, Nepal	
Variable	Rangpur	Rajshahi	Madhubai	Purnea	Malda	Cooch Behar	Dhanusha	Sunsari
Cultivator cost (A$/ha)	nd	nd	nd	100–105	nd	nd	nd	43–50
Rotavator cost (A$/ha)	nd	76	nd	nd	86–89	85–89	77–93	46–54
Rice transplanter (A$/ha)	nd	38	nd	nd	74	89–92	nd	72
DSR/strip till (A$/ha)	nd	nd	59	42	59	59–62	77	nd
PTOS (A$/ha)	34	60	nd	nd	nd	nd	nd	nd
Power tiller for tilling (A$/ha)	30–32	78–79	nd	nd	nd	nd	nd	nd
Power tiller for puddling and levelling (A$/ha)	51–53	nd	nd	nd	nd	nd	nd	nd
Tractor (A$/ha)	nd	nd	149	nd	nd	nd	65–68	nd

A$ = Australian dollars; DSR = direct-seeded rice; nd = no data available; PTOS = power tiller-operated seeder
Sources: SRFSI field data. Cropping Intensity: Bangladesh Bureau of Statistics (2016), Indian Department of Agriculture Cooperation and Farmers Welfare (2017), Ministry of Agriculture Development (2013)

For instance, the wage rate was highest in Dhanusha (A$5.59/day) and lowest in Madhubani (A$2.97/day), and the irrigation charge per hour was highest in Bihar and Cooch Behar (A$2.18/h) and lowest in Nepal (A$1.37/h). Although Nepal uses diesel for irrigation—which is costly—the irrigation charge per hour there was lower because of the subsidised diesel price.

The wage difference between Rangpur (A$4.26/day) and Rajshahi (A$5.11/day) was A$0.85/day, but the irrigation charge was A$0.17/h lower in Rajshahi. Although the labour wage in Purnea was higher than in Madhubani by A$0.87/day, the irrigation charge (A$2.18/h) was the same in both districts. Similarly, in Nepal, the difference in wage rate was A$0.62/day between Dhanusha (A$5.59/day) and Sunsari (A$4.96/day), and the irrigation charge per hour was the same in both districts.

The wage rate and irrigation charge differences were also present in West Bengal. The wage rate was higher in Cooch Behar than in Malda by A$1.00/day. Likewise, the irrigation charge was A$0.20/h lower in Malda than in Cooch Behar, even though Cooch Behar uses electric pumps for irrigation. One of the reasons for the higher irrigation charge was because diesel pumps are used for irrigation.

Machinery used for land preparation differed across all regions (Table 5.2–5.3). For example, for Aman rice, a rotavator rice transplanter was used in Rajshahi and Malda. A power tiller-operated seeder and a power tiller were being used in Rajshahi and Rangpur, and, in some Dhanusha nodes and in Madhubani, a tractor was used to prepare plots.

Hiring charges for land-preparation machinery also differed. The hiring charge of the machinery in Rajshahi was >100% higher than in Rangpur (Tables 5.2–5.3). The reason for price differences for power tiller-operator seeders and strip tills was that different partners implement the project

Table 5.3 Variation of major inputs for wheat across SRFSI working districts, 2015–16

	North-west Bangladesh		Bihar, India		West Bengal, India		Terai, Nepal	
Variable	Rangpur	Rajshahi	Madhubai	Purnea	Malda	Cooch Behar	Dhanusha	Sunsari
Cultivator cost (A$/ha)	nd	nd	nd	118	74–89	77–80	nd	62
Rotavator cost (A$/ha)	nd	nd	nd	nd	74–89	92–101	nd	77
Zero till (A$/ha)	nd	nd	54	69	59	59	77	77
Harrow (A$/ha)	nd	nd	152	nd	nd	nd	nd	nd
Power tiller for tilling (A$/ha)	30–32	75–85	nd	nd	nd	nd	nd	nd
Strip till (A$/ha)	43	60–64	nd	nd	nd	nd	nd	nd

A$ = Australian dollars; nd = no data available
Sources: SRFSI field data. Cropping Intensity: Bangladesh Bureau of Statistics (2016), Indian Department of Agriculture Cooperation and Farmers Welfare (2017), Ministry of Agriculture Development (2013)

in these districts, and the implementing institutions were providing the machinery.

In Nepal, the hiring charge was higher in Dhanusha than in Sunsari (Table 5.2) because Sunsari had better infrastructure and four-wheeled tractors were readily available. In Dhanusha, they had to be hired from India because very few farmers owned four-wheeled tractors in Dhanusha. This scenario was similar for Madhubani. In West Bengal, there was only a slight difference in hiring rates.

The variation in machinery hiring charge affects the cropping intensity, especially in Bangladesh where the cropping intensity in Rangpur is higher than in Rajshahi (Table 5.1). However, this is not the case in other nodes. This is because Nepalese data are from 2012–13 data and Indian data are from 2014–15. Other factors can also affect cropping intensity, such as labour availability, irrigation facilities, the land tenure system and climate.

Economic analysis and annual variations of cropping systems across the Eastern Gangetic Plains, 2014–15 and 2015–16

This section compares the annual yields, returns, benefits, time required for irrigation and labour productivity for 2014–15 and 2015–16 across different systems and different districts. We will also present annual variation for these parameters.

Long-term core trial data were used for the analysis. We could not compute water use efficiency, because information on pump discharge rate was not available for all the areas. Therefore, we have compared the time required for irrigation when using zero till and conventional till.

Bangladesh

Table 5.4 compares productivity, profitability, labour used, tillage or seeding, and irrigation time required for a rice–maize system in 2014–15 and 2015–16 under different tillage options. Yield was lower in 2015–16 for the conventional tilled transplanted rice – conventional tilled maize (CTTPR-CTM) system than in 2014–15 for both Rangpur and Rajshahi by 4.29% and 0.06%, respectively. In Rajshahi, for unpuddled transplanted rice – zero-tilled maize (UPTPR-ZTM) and zero-tilled direct-seeded rice – zero-tilled maize (ZTDSR-ZTM), yield was lower in 2015–16 by 1.47% and 2.12%, respectively. In Rangpur, yield was higher in 2015–16 for all treatments that used zero tillage. The percentage increase in yield was highest under ZTDSR-ZTM (10.84%) and lowest with UPTPR-ZTM (3.48%) in Rangpur.

However, in the CTTPR-CTM system, net profit had increased by 0.44% in 2015–16 in Rajshahi, but in Rangpur it reduced by 7.26% due to increased irrigation costs. The highest percentage increase in net profit was in Rangpur in the ZTDSR-ZTM system (9.65%). Compared with 2014–15, the benefit–cost ratio was less for all the practices in both Rangpur and Rajshahi in 2015–16, which was attributed to increases in irrigation hours and, consequently, the cost of irrigation.

The percentage increase in labour productivity was highest in Rangpur in 2015–16 in the CTTPR-CTM system (17%); labour productivity decreased by 1.63% and 18.46% in the ZTDSR-ZTM and UPTPR-ZTM systems, respectively.

Table 5.5 compares the rice–wheat system in Rajshahi and the rice–wheat–jute system in Rangpur under different tillage options, including conventional tilled jute (CTJ) and zero-tilled jute (ZTJ). Yield for all treatments was less in 2015–16, and irrigation time and cost increased significantly. The percentage

Table 5.4 Productivity, profitability, labour used, tillage or seeding, and irrigation time required for a rice–maize system under different tillage options in Bangladesh, 2014–15 and 2015–16

		CTTPR-CTM		CTTPR-ZTM		ZTDSR-ZTM		UPTPR-ZTM	
Variable	Year	Rajshahi	Rangpur	Rajshahi	Rangpur	Rajshahi	Rangpur	Rajshahi	Rangpur
Grain yield (t/ha)	2014–15	12.34	16.23	12.22	16.68[a]	12.71	16.52	12.93[a]	16.67
	2015–16	11.81	16.22	12.48	17.36	12.44	18.31[a]	12.74[a]	17.25
Biomass (t/ha)	2014–15	29.95	38.95	32.33	40.38[a]	35.08[a]	37.38	34.09	39.21
	2015–16	28.32	38.17	29.93	39.1[a]	33.22[a]	26.29	33.19	38.70
Production cost (A$/ha)	2014–15	1,777	1,798	1,648	1,653	1,469[a]	1,512[a]	1,494	1,573
	2015–16	1,988	1,945	1,911	1,780	1,708[a]	1,662[a]	1,822	1,671
Gross return (A$/ha)	2014–15	3,806	5,131	3,783	5,262[a]	4,082[a]	5,128	4,058	5,238
	2015–16	4,027	5,032	4,236	5,352	4,283	5,625[a]	4,383[a]	5,316
Net profit (A$/ha)	2014–15	2,029	3,333	2,134	3,609	2,613[a]	3,616	2,563	3,665[a]
	2015–16	2,038	3,091	2,324	3,576	2,576[a]	3,965[a]	2,561	3,648
Benefit–cost ratio	2014–15	1.10	1.83	1.27	2.13	1.72[a]	2.35[a]	1.66	2.28
	2015–16	1.04	1.51	1.22	1.91	1.54[a]	2.24[a]	1.42	2.07
Irrigation time (h/ha)	2014–15	45.26	41.05	40.21	33.11	39.25	30.08[a]	38.61[a]	31.37
	2015–16	71.40	45.32	64.13	35.27	56.19	34.03[a]	56.00[a]	34.15
Labour productivity (A$/ha)	2014–15	3.47	3.58	4.59	4.60	6.80[a]	5.88	6.59	11.14[a]
	2015–16	4.05	3.72	4.90	4.96	6.69[a]	5.67	5.37	11.17[a]

A$ = Australian dollar; CTM = conventional tilled maize; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-till direct-seeded rice; ZTM = zero-tilled maize
a Best value for each district, indicating which treatment was best.

yield loss was higher for Rangpur in the CTTPR-CTW-CTJ (11%) and UPTPR-ZTW-ZTJ (12%) systems, and for Rajshahi loss percentage is highest in CTTPR-CTW (by 12%). Similarly, the biomass and net profit also decreased. There were no trials of ZTDSR-ZTW-ZTJ in 2014–15.

Note that 2015–16 had less rainfall than 2014–15. In Rajshahi, this resulted in a higher crop loss in the CTTPR-CTW system (12%) than in the CTTPR-ZTW system compared with 2014–15. Irrigation time was also longer in 2015–16, increasing 49% for the CTTPR-CTW system and 47% for the CTTPR-ZTW system from the 2014–15 levels. For the ZTDSR-ZTW system, yield fell 3%, and 37% more time was required for irrigation. UPTPR-ZTW had the smallest increase (30%) in irrigation time. This confirmed that the zero-till system was more climate-resilient than conventional till systems, and lessens the yield lost in bad years. Aryal et al. (2016) showed similar results for zero tilling in Haryana

Table 5.5 Productivity, profitability, irrigation time required and labour productivity for a rice–wheat system in Rajshahi and a rice–wheat–jute system in Rangpur under different tillage options, 2014–15 and 2015–16

		CTTPR-CTW	CTTPR-CTW-CTJ	CTTPR-ZTW	CTTPR-ZTW-ZTJ	ZTDSR-ZTW	ZTDSR-ZTW-ZTJ	UPTPR-ZTW	UPTPR-ZTW-ZTJ
Variable	**Year**	**Rajshahi**	**Rangpur**	**Rajshahi**	**Rangpur**	**Rajshahi**	**Rangpur**	**Rajshahi**	**Rangpur**
Grain yield (t/ha)	2014–15	8.05[a]	11.48	7.65	11.83	7.80	nt	7.83	12.20[a]
	2015–16	7.09	10.25	7.60	10.56	7.58	10.81[a]	7.75[a]	10.79
Biomass (t/ha)	2014–15	20.13	33.22[a]	20.51	30.31	21.21	nt	23.33[a]	30.85
	2015–16	17.90	23.94	19.15	26.65	20.94	26.90[a]	21.20[a]	26.69
Production cost (A$/ha)	2014–15	1,616	1,960	1,446	1,782	1,260[a]	nt	1,291	1,723[a]
	2015–16	1,622	1,906	1,553	1,776	1,369[a]	1,662[a]	1,438	1,664
Gross return (A$/ha)	2014–15	2,894	5,403	2,849	5,479	2,923	nt	2,993[a]	5,647[a]
	2015–16	2,937	4,243	3,161	4,464	3,190	4,550[a]	3,254[a]	4,519
Net profit (A$/ha)	2014–15	1,277	3,443	1,404	3,697	1,663	nt	1,701[a]	3,924[a]
	2015–16	1,315	2,457	1,608	2,840	1,822[a]	3,041[a]	1,815	3,010
Benefit–cost ratio	2014–15	0.78	1.97	0.99	2.23	1.32[a]	nt	1.31	2.44[a]
	2015–16	0.81	1.45	1.06	1.79	1.36[a]	1.97[a]	1.27	1.93
Irrigation time (h/ha)	2014–15	38.44	59.00	33.78	43.47	32.15[a]	nt	34.26[a]	43.31
	2015–16	57.17	62.55	49.70	51.82[a]	43.81[a]	51.82[a]	44.37	52.63
Labour productivity (A$/ha)	2014–15	2.76	3.16	3.71	3.74	5.37[a]	nt	5.27	4.25[a]
	2015–16	3.14	2.93	3.76	3.62	5.18[a]	3.92[a]	4.57	3.90

A$ = Australian dollar; CTJ = conventional tilled jute; CTW = conventional tilled wheat; CTTPR = conventional tilled transplanted rice; nt = no trials done; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTJ = zero-tilled jute; ZTW = zero-tilled wheat

a Best value for each district, indicating which treatment was best.

after untimely excess rainfall in 2014–15. In Rangpur, the yield loss was highest in the system preceded by conventional practice (11%) and lowest (1%) with the UPTPR-ZTW-ZTJ system. The irrigation time required was highest with UPTPR-ZTW-ZTJ (22% more in 2015–16) and lowest with the CTPR-CTW-CTJ system.

Although the cost of tillage was reduced, other costs of cultivation—mainly irrigation—increased. This reduced the net profits significantly, especially in Rangpur. Rajshahi managed higher positive net profits despite the bad year in 2015–16. The highest percentage of net profit in 2014–15 was 15% with the CTTPR-ZTW system and lowest with CTTPR-CTW. Labour productivity was also lower in 2015–16 in Rangpur than in Rajshahi.

Bihar

Table 5.6 summaries the key results for the rice–wheat system for 2014–15 and 2015–16 under different tillage options in Bihar. In Madhubani, compared with 2014–15, yield increased in 2015–16 by 16% for ZTDSR-ZTW and by 17% for CTTPR-ZTW and UPTPR-ZTW.

For Purnea, the yield reduced in all treatments except ZTDSR-ZTW in 2015–16. In ZTDSR-ZTW, yield was slightly higher (by 1%) in 2015–16. However, the biomass was higher for all systems in Purnea in 2015–16—8% higher for ZTDSR-ZTW and lowest for UPTPR-ZTW compared with 2014–15. In Madhubani, biomass was less in 2015–16 than in 2014–15, although the yield was higher.

Gross return was lower for all the practices in both Madhubani and Purnea because of a decrease in price, which was reflected in net profit and the benefit–cost ratio.

In Madhubani, irrigation time and cost increased in 2015–16. Compared with 2014–15, the longest time required for irrigation was for CTTPR-ZTW (175% higher) and the lowest was for ZTDSR-ZTW (115%). Labour productivity increased in 2015–16 compared with 2014–15. In Purnea, the percentage increase in labour

Table 5.6 Productivity, profitability, irrigation time required and labour productivity for rice–wheat systems under different tillage options in Bihar, 2014–15 and 2015–16

Variable	Year	CTTPR-CTW		CTTPR-ZTW		ZTDSR-ZTW		UPTPR-ZTW	
		Madhubani	Purnea	Madhubani	Purnea	Madhubani	Purnea	Madhubani	Purnea
Grain yield (t/ha)	2014–15	nt	7.75	5.12	8.62[a]	5.35[a]	7.52	5.27	8.46
	2015–16	5.88	7.32	5.99	7.38	6.23[a]	7.57[a]	6.17	7.11
Biomass (t/ha)	2014–15	nt	17.50	14.04	17.99[a]	14.84[a]	17.06	14.55	17.63
	2015–16	13.38	17.98	13.61	18.17	14.03[a]	18.50[a]	13.93	17.75
Production cost (A$/ha)	2014–15	nt	1,436	1,158	1,335	1,051[a]	1,057[a]	1,151	1,212
	2015–16	1,451	1,657	1,337	1,430	1,165[a]	1,149[a]	1,219	1,305
Gross return (A$/ha)	2014–15	nt	2,918	2,277	3,192[a]	2,389[a]	2,832	2,351	3,129
	2015–16	1,774	2,726	1,813	2,754	1,873[a]	2,819[a]	1,866	2,661
Net profit (A$/ha)	2014–15	nt	1,483	1,118	1,857	1,338[a]	1,775	1,200	1,917[a]
	2015–16	322	1,069	476	1,324	707[a]	1,670[a]	647	1,356
Benefit–cost ratio	2014–15	nt	1.02	1.92	1.41	2.40[a]	1.68[a]	2.00	1.60
	2015–16	1.24	0.68	1.41	0.96	1.63[a]	1.53[a]	1.57	1.06
Irrigation time (h/ha)	2014–15	nt	101.81	19.74[a]	97.95	19.74[a]	95.84[a]	19.74[a]	96.51
	2015–16	61.94	57.32	54.21	43.82	42.46[a]	36.22[a]	48.48	44.58
Labour productivity (A$/ha)	2014–15	2.24	2.52	2.57	3.60	3.50[a]	2.62[a]	3.23	2.52
	2015–16	4.41	4.59	5.35	5.87[a]	9.84[a]	4.48	6.77	4.59

A$ = Australian dollar; CTW = conventional tilled wheat; CTTPR = conventional tilled transplanted rice; nt = no trials done; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTW = zero-tilled wheat

a Best value for each district, indicating which treatment was best.

productivity was highest for the ZTDSR-ZTW system (181%) and lowest for CTTPR-CTW (97%). This was expected because the ZTDSR system needs less labour for rice transplantation. In Madhubani, labour productivity was highest for UPTPR-ZTW (71%) and lowest for ZTDSR-ZTW (63%). This could be because of gap filling in ZTDSR, as farmers mentioned that sowing was not even with zero tillage, due to the unavailability of skilled drivers.

Table 5.7 presents the results for the rice–maize system for 2014–15 and 2015–16 under different tillage options in Purnea. Compared with 2014–15, the yield of maize increased in 2015–16 regardless of the treatment. However, the percentage gain in maize yield was highest in the ZTDSR-ZTM system (21%) and lowest in the CTTPR-CTM system. This was reflected in biomass production, net profit, benefit–cost ratio and labour productivity. Production costs increased by 13% in 2015–16 for both CTTPR-CTM and ZTDSR-ZTM.

Nepal

Table 5.8 presents the results for the rice–wheat system for 2014–15 and 2015–16 under different tillage options in Nepal. In 2015–16 in Dhanusha, yield was higher for

Table 5.7 Productivity, profitability, irrigation time required and labour productivity for the rice–maize system under different tillage options in Purnea, 2014–15 and 2015–16

Variable	Year	CTTPR-CTM	CTTPR-ZTM	ZTDSR-ZTM	UPTPR-ZTM
Grain yield (t/ha)	2014–15	12.69[a]	11.94	11.55	11.60
	2015–16	13.57	13.57	13.98[a]	13.78
Biomass (t/ha)	2014–15	28.48[a]	26.85	26.08	26.29
	2015–16	32.49	32.43	33.20[a]	32.98
Production cost (A$/ha)	2014–15	1,629	1,419	1,229[a]	1,294
	2015–16	1,846	1,654	1,383[a]	1,525
Gross return (A$/ha)	2014–15	4,203[a]	3,977	3,832	3,854
	2015–16	4,481	4,505	4,652[a]	4,484
Net profit (A$/ha)	2014–15	2,574	2,559	2,603[a]	2,560
	2015–16	2,634	2,851	3,269[a]	2,959
Benefit–cost ratio	2014–15	1.56	1.84	2.10[a]	1.97
	2015–16	2.81	3.44	4.75[a]	3.73
Irrigation time (h/ha)	2014–15	105.21	96.13	91.64[a]	97.98
	2015–16	154.93	130.32	115.90[a]	129.63
Labour productivity (A$/ha)	2014–15	2.89	3.19	4.24[a]	3.98
	2015–16	3.42	4.08	7.27[a]	5.00

A$ = Australian dollar; CTM = conventional tilled maize; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTM = zero-tilled maize
a Best value for each district, indicating which treatment was best.

Table 5.8 Productivity, profitability, irrigation time required and labour productivity for the rice–wheat system under different tillage options in Nepal, 2014–15 and 2015–16

Variable	Year	CTTPR-CTW		CTTPR-ZTW		ZTDSR-ZTW		UPTPR-ZTW	
		Dhanusha	Sunsari	Dhanusha	Sunsari	Dhanusha	Sunsari	Dhanusha	Sunsari
Grain yield (t/ha)	2014–15	6.50	8.09	6.58	9.10[a]	6.70[a]	8.36	6.51	8.82
	2015–16	7.82	8.29	7.88	8.80[a]	7.94[a]	8.65	7.86	8.54
Biomass (t/ha)	2014–15	16.44	18.25	16.36	19.90[a]	16.81[a]	18.25	16.64	19.29
	2015–16	18.16	18.48	17.82	19.27[a]	18.30[a]	19.04	17.83	18.98
Production cost (A$/ha)	2014–15	1,239	1,146	1,180	1,143[a]	981[a]	1,264	1,154	1,398
	2015–16	1,510	1,474	1,426	1,401	1,113[a]	1,114[a]	1,268	1,215
Gross return (A$/ha)	2014–15	2,971	3,012	3,004	3,172[a]	3,054[a]	3,001	2,986	2,889
	2015–16	2,953	3,502	2,940	3,774	2,986[a]	3,417	2,942	3,807[a]
Net profit (A$/ha)	2014–15	1,733	1,866	1,825	2,029[a]	2,073[a]	1,737	1,832	1,491
	2015–16	1,444	2,028	1,514	2,373	1,873[a]	2,303	1,674	2,592[a]
Benefit–cost ratio	2014–15	1.44	1.59	1.63	2.12[a]	2.09[a]	1.59	1.61	1.07
	2015–16	3.30	1.41	3.85	1.70	4.55[a]	2.16	4.06	2.33[a]
Irrigation time (h/ha)	2014–15	68.69	40.00	51.22[a]	37.63[a]	52.57	41.94	59.05	34.85
	2015–16	34.88	46.02	33.36[a]	37.50	33.58	37.71	33.18[a]	37.12
Labour productivity (A$/ha)	2014–15	2.65	4.28	3.24	4.66[a]	5.96[a]	3.35	3.93	3.03
	2015–16	2.66	4.38	3.28	4.67	7.32[a]	7.00	4.09	7.80[a]

A$ = Australian dollar; CTW = conventional tilled wheat; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTW = zero-tilled wheat
a Best value for each district, indicating which treatment was best.

all treatments than in 2014–15. The UPTPR-ZTW system had the highest percentage yield increase (21%), followed by CTTPR-CTW (20%) and CTTPR-ZTW (21%), and then ZTDSR-ZTW (19%). However, in Sunsari, yield and biomass reduced by 3% for CTTPR-ZTW and 2% for UPTPR-ZTW.

For ZTDSR-ZTW and CTTPR-CTW, yield increased by 3% and 2%, respectively, and biomass by 4% and 1%, respectively. Except for ZTDSR-ZTW and UPTPR-ZTW in Sunsari, the production cost increased for all treatments in Dhanusha and Sunsari. Although yield increased in Dhanusha, gross returns and net profit decreased in 2015–16 because of increases in production costs and decreases in price. The rise in production cost was highest for the CTTPR-CTW system (22%) and lowest for the UPTPR-ZTW system (10%). The benefit–cost ratio increased for all treatments in 2015–16, and was highest for the UPTPR-ZTW system (152%) and lowest for the ZTDSR-ZTW system (118%).

The percentage increase in labour productivity was highest in the UPTPR-ZTW system (4%) but there was no change for the CTTPR-CTW system.

In Sunsari, yield reduced by 3% for UPTPR-ZTW, but this system had the highest net profit increase (44%) and labour productivity (157%). Yield was lowest for CTTPR-CTW, which had a 9% net profit increase, a 2% labour productivity increase and an 11% benefit–cost ratio decrease.

Table 5.9 presents the results for the rice–lentil system for 2014–15 and 2015–16 in Nepal under different tillage practices, including conventional tilled lentil (CTL) and zero-tilled lentil (ZTL). In Dhanusha, yield was lower in 2015–16 for all systems. The reduction in yield was highest for CTTPR-CTW (45%) and lowest for UPTPR-ZTW (41%), but the net profit (74%), benefit–cost ratio (62%) and labour productivity (49%) all increased. The reduction in yield was lowest for UPTPR-ZTW (41%), but this system also had the highest reduction in biomass (by 25%), and the lowest percentage increases in net profit (67%), benefit–cost ratio (40%) and labour productivity (3%).

In Sunsari, yield was higher in 2015–16 for all systems. The highest percentage increase in yield was for CTTPR-ZTL (31%) and the lowest was for CTTPR-CTL (10%). For the other two practices, the percentage increase in yield was more than 20%. Similarly, for ZTDSR-ZTL, net profit increased by 30% and the benefit–cost ratio by 61%.

Table 5.9 Productivity, profitability, irrigation time required and labour productivity for the rice–lentil system under different tillage options in Nepal, 2014–15 and 2015–16

		CTTPR-CTL		CTTPR-ZTL		ZTDSR-ZTL		UPTPR-ZTL	
Variable	**Year**	Dhanusha	Sunsari	Dhanusha	Sunsari	Dhanusha	Sunsari	Dhanusha	Sunsari
Grain yield (t/ha)	2014–15	7.51	6.59[a]	7.60[a]	6.06	7.43	6.32	7.39	6.19
	2015–16	4.15	7.22	4.23	7.96[a]	4.34	7.89	4.35[a]	7.95
Biomass (t/ha)	2014–15	16.38	12.86	16.41	12.37	16.80[a]	13.39[a]	16.76	12.54
	2015–16	12.98	16.02	13.02	17.00	13.04[a]	17.42	12.64	17.56[a]
Production cost (A$/ha)	2014–15	1,059	1,090	1,031	901	863[a]	695[a]	863[a]	974
	2015–16	1,239	1,137	1,237	1,162	854[a]	863[a]	1,084	1,005
Gross return (A$/ha)	2014–15	4,465	3,967	4,597	5,152[a]	4,719[a]	3,536	4,650	4,684
	2015–16	7,175	4,010	7,249	4,518	7,396	4,552	7,409[a]	4,746[a]
Net profit (A$/ha)	2014–15	3,405	2,877	3,566	4,251[a]	3,856[a]	2,841	3,788	3,710
	2015–16	5,936	2,873	6,012	3,356	6,542[a]	3,689	6,325	3,741[a]
Benefit–cost ratio	2014–15	4.61	7.07[a]	5.30	4.43	5.89[a]	4.05	5.77	4.52
	2015–16	7.45	5.11	7.56	5.87	9.09[a]	6.54	8.07	6.67[a]
Irrigation time (h/ha)	2014–15	nd	27.78	nd	0[a]	nd	0[a]	nd	0
	2015–16	nd	68.75	nd	75.00	nd	62.50[a]	nd	87.50
Labour productivity (A$/ha)	2014–15	5.53	5.33	5.75	7.24	9.83	10.05[a]	9.69[a]	6.73
	2015–16	8.21	5.22	8.30	5.94	21.46[a]	11.16[a]	9.93	10.59

A$ = Australian dollar; CTL = conventional tilled lentil; CTTPR = conventional tilled transplanted rice; nd = data not available; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTL = zero-tilled lentil
a Best value for each district, indicating which treatment was best.

For CTTPR-CTL, although the cost of production fell by 4%, there was very negligible increase in net profit; the benefit–cost ratio decreased by 28% and labour productivity fell by 2%. The percentage increase in labour productivity was highest for UPTPR-ZTL (57%), but it decreased by 18% for CTTPR-ZTL. This could be because rice transplanting needs more labour.

Table 5.10 presents the results for the rice–maize system for 2014–15 and 2015–16 in Sunsari under different tillage practices. Yield was lower in 2015–16 regardless of the practice, but the percentage fall in yield was lowest for UPTPR-ZTM (15%) and highest for ZTDSR-ZTM. However, ZTDSR-ZTM had the largest reduction in production cost and the lowest reduction in net profit in 2015–16.

In 2015–16, production cost increased the most for CTTPR-CTM (41%). For CTTPR-CTM in 2015–16, there were decreases in net profit (by 21%), the benefit–cost ratio (by 29%), grain yield (by 20%) and labour productivity (by 1%) compared with the previous year.

Table 5.11 presents the results for the rice–maize system for 2014–15 and 2015–16 in West Bengal under different tillage practices. Yield increased for all systems in 2015–16 compared with 2014–15.

Table 5.10 Productivity, profitability, irrigation time required and labour productivity for the rice–maize system under different tillage options in Sunsari, 2014–15 and 2015–16

Variable	Year	CTTPR-CTM	CTTPR-ZTM	ZTDSR-ZTM	UPTPR-ZTM
Grain yield (t/ha)	2014–15	15.00	14.50	15.29	14.10
	2015–16	11.98	11.50	11.45	12.01
Biomass (t/ha)	2014–15	31.71	31.70	32.52	30.70
	2015–16	25.59	24.63	24.69	25.69
Production cost (A$/ha)	2014–15	1,248[a]	1,299	1,365	1,307
	2015–16	1,756	1,604	1,200[a]	1,350
Gross return (A$/ha)	2014–15	3,752	3,650	3,747	3,768[a]
	2015–16	3,731	3,562	3,568	3,740[a]
Net profit (A$/ha)	2014–15	2,504[a]	2,351	2,382	2,461
	2015–16	1,974	1,957	2,369	2,389[a]
Benefit–cost ratio	2014–15	1.68	1.72	1.69[a]	1.53
	2015–16	1.20	1.32	2.04[a]	1.86
Irrigation time (h/ha)	2014–15	42.23	40.72[a]	41.67	42.61
	2015–16	79.24	56.23	56.16[a]	58.68
Labour productivity (A$/ha)	2014–15	3.66	4.11	8.84[a]	7.14
	2015–16	3.64	4.01	8.42[a]	7.08

A$ = Australian dollar; CTM = conventional tilled maize; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTM = zero-tilled maize
a Best value for each district, indicating which treatment was best.

Table 5.11 Productivity, profitability, irrigation time required and labour productivity for the rice–maize system under different tillage options in West Bengal, 2014–15 and 2015–16

Variable	Year	CTTPR-CTM		CTTPR-ZTM		UPTPR-CTM	ZTDSR-ZTM	UPTPR-ZTM	
		Cooch Behar	Malda	Cooch Behar	Malda	Cooch Behar	Malda	Cooch Behar	Malda
Grain yield (t/ha)	2014–15	12.58[a]	11.75	12.50	12.38	12.50	12.89[a]	12.50	12.47
	2015–16	12.74	12.31	12.78	12.81	13.47[a]	13.62	13.29	13.66[a]
Biomass (t/ha)	2014–15	32.33[a]	29.91	32.33[a]	31.04	32.33[a]	32.45[a]	32.33[a]	31.59
	2015–16	33.64	35.59	34.30[a]	36.96	34.15	38.75[a]	33.74	37.63
Production cost (A$/ha)	2014–15	1,616	1,859	1,213[a]	1,631	1,213[a]	1,367[a]	1,213[a]	1,446
	2015–16	1,631	1,948	1,592	1,743	1,322	1,707	1,278[a]	1,624[a]
Gross return (A$/ha)	2014–15	3,773[a]	4,204	3,759	4,437	3,759	4,622[a]	3,759	4,469
	2015–16	4,170	4,677	4,202	4,875	4,356[a]	5,168[a]	4,295	5,119
Net profit (A$/ha)	2014–15	2,157	2,346	2,546[a]	2,806	2,546[a]	3,255[a]	2,546[a]	3,023
	2015–16	2,539	2,729	2,610	3,132	3,034[a]	3,461	3,017	3,495[a]
Benefit–cost ratio	2014–15	1.31	1.19	2.08[a]	1.72	2.08[a]	2.23[a]	2.08[a]	2.00
	2015–16	1.49	1.55	1.58	2.13	2.32	2.34	2.40[a]	2.45[a]
Irrigation time (h/ha)	2014–15	29.69	65.47	26.96[a]	57.68	26.96[a]	57.17	26.96[a]	54.36[a]
	2015–16	40.72	67.13	40.72	58.33	33.94[a]	56.58	33.94[a]	50.67[a]
Labour productivity (A$/ha)	2014–15	3.42	2.87	7.23[a]	4.17	7.23[a]	7.31[a]	7.23[a]	7.25
	2015–16	3.57	4.68	4.69	6.70	5.45	9.36	8.10	9.41

A$ = Australian dollar; CTM = conventional tilled maize; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTM = zero-tilled maize
a Best value for each district, indicating which treatment was best.

In Cooch Behar, percentage increase in yield was highest for UPTPR-CTM (8%) and lowest for CTTPR-CTM (1%). The percentage increase in net profit was also highest for UPTPR-CTM (19%) and lowest for CTTPR-ZTM (3%). The benefit–cost ratio also decreased by 24%, and labour productivity was highest for UPTPR-ZTM (11%).

In Malda, the highest percentage increase in yield was for UPTPR-ZTM (10%) and the lowest was for CTTPR-ZTM (3%). The percentage increase in net profit was highest for both UPTPR-ZTM and CTTPR-CTM (16%) and lowest for ZTDSR-ZTM (6%). However, labour productivity was highest for CTTPR-CTM (63%) and lowest for ZTDSR-ZTM. The benefit–cost ratio was also highest for CTTPR-CTM (by 30%) and lowest for ZTDSR-ZTM.

Table 5.12 presents the results from West Bengal for the rice–wheat system in Cooch Behar and the rice–wheat–mungbean system in Malda for 2014–15 and 2015–16 under different tillage practices. Yield decreased in 2015–16 compared with 2014–15 for all systems.

In Cooch Behar, the percentage decrease in yield was lowest for UPTPR-ZTW (8%) and highest for CTTPR-ZTW (15%). The percentage decrease in net profit was also lowest for UPTPR-ZTW (5%) and highest for CTTPR-ZTW (34%). The reduction in the benefit–cost ratio is also highest for CTTPR-ZTW (42%) but lowest for CTTPR-CTW (10%).

In Malda, the highest percentage decrease in yield was for UPTPR-ZTW-MB (7%) and the lowest percentage decrease was for CTTPR-ZTW-MB (4%). The percentage

Table 5.12 Productivity, profitability, irrigation time required and labour productivity for the rice–wheat system in Cooch Behar and the rice–wheat–mungbean system in Malda under different tillage options, 2014–15 and 2015–16

Variable	Year	CTTPR-CTW	CTTPR-CTW-MB	CTTPR-ZTW	CTTPR-ZTW-MB	UPTPR-CTW	ZTDSR-ZTW-MB	UPTPR-ZTW	UPTPR-ZTW-MB
		Cooch Behar	Malda	Cooch Behar	Malda	Cooch Behar	Malda	Cooch Behar	Malda
Grain yield (t/ha)	2014–15	7.65	8.67	7.79	8.95	7.91[a]	9.41	7.91[a]	9.42[a]
	2015–16	6.55	8.22	6.64	8.63	6.88	8.74[a]	7.29[a]	8.74[a]
Biomass (t/ha)	2014–15	19.32	24.80	20.20	24.75	20.59[a]	25.56[a]	20.59[a]	25.19
	2015–16	17.00	26.36	17.28	26.85[a]	17.67	26.68	18.78[a]	26.73
Production cost (A$/ha)	2014–15	1,689	2,366	1,408	1,906	1,266[a]	1,675[a]	1,266[a]	1,737
	2015–16	1,638	2,426	1,610	2,093	1,346	2,054	1,340[a]	1,977[a]
Gross return (A$/ha)	2014–15	2,580	3,818	2,665	3,955	2,704[a]	4,084[a]	2,704[a]	4,064
	2015–16	2,411	3,877	2,440	4,083	2,545	4,062	2,699[a]	4,085
Net profit (A$/ha)	2014–15	890	1,453	1,257	2,050	1,438[a]	2,409[a]	1,438[a]	2,327
	2015–16	773	1,451	830	1,990	1,199	2,008	1,360[a]	2,108[a]
Benefit–cost ratio	2014–15	0.54	0.57	0.91	1.10	1.14[a]	1.39[a]	1.14[a]	1.29
	2015–16	0.51	0.72	0.57	1.38	0.87	1.27	1.00[a]	1.41[a]
Irrigation time (h/ha)	2014–15	31.24	72	27.33[a]	63	27.33[a]	62[a]	27.33[a]	62[a]
	2015–16	53.26	93	53.26	82	46.89[a]	79	47.51	77[a]
Labour productivity (A$/ha)	2014–15	2.16	2.01	3.23	3.23	5.20[a]	5.26[a]	5.20[a]	5.24
	2015–16	1.87	2.9	2.38	4.6	2.95	5.71	4.5	5.8

A$ = Australian dollar; CTW = conventional tilled wheat; CTTPR = conventional tilled transplanted rice; MB = mungbean; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTW = zero-tilled wheat

a Best value for each district, indicating which treatment was best.

decrease in net profit was highest for ZTDSR-ZTW-MB (17%) and lowest for CTTPR-CTW-MB (<1%). Therefore, the reduction in the benefit–cost ratio was lowest for CTTPR-CTW-MB (3%) and highest for ZTDSR-ZTW-MB (32%).

Table 5.13 presents the results from West Bengal for the rice–lentil system in Cooch Behar and the rice–lentil–mungbean system in Malda for 2014–15 and 2015–16 under different tillage practices. Yield increased for all treatments and all practices in 2015–16 compared with 2014–15, except for the ZTDSR-ZTL-MB system in Malda.

Table 5.13 Productivity, profitability, irrigation time required and labour productivity for the rice–lentil system in Cooch Behar and rice–lentil–mungbean system in Malda under different tillage options, 2014–15 and 2015–16

		CTTPR-CTL	CTTPR-CTL-MB	CTTPR-ZTL	CTTPR-ZTL-MB	UPTPR-CTL	ZTDSR-ZTL-MB	UPTPR-ZTL	UPTPR-ZTL-MB
Variable	**Year**	**Cooch Behar**	**Malda**	**Cooch Behar**	**Malda**	**Cooch Behar**	**Malda**	**Cooch Behar**	**Malda**
Grain yield (t/ha)	2014–15	6.91	6.34	7.05[a]	6.67	6.77	7.31[a]	6.69	7.24
	2015–16	8.37	6.68	8.44	7.42[a]	8.60	7.15	8.85[a]	7.41
Biomass (t/ha)	2014–15	16.27	16.88	16.44	18.82	16.81[a]	18.44	16.78	19.20[a]
	2015–16	19.92	19.26	19.91	19.46[a]	20.54[a]	18.68	20.46	19.41
Production cost (A$/ha)	2014–15	1,137	2,058	1,137	1,612	969	1,379[a]	793[a]	1,446
	2015–16	1,648	1,842	1,637	1,610[a]	1,609	1,710	1,484[a]	1,718
Gross return (A$/ha)	2014–15	3,172	4,384	3,357[a]	4,479	3,327	5,007[a]	3,233	4,985
	2015–16	5,115	5,084	5,235	5,491	5,262	5,253	5,487[a]	5,547[a]
Net profit (A$/ha)	2014–15	2,036	2,326	2,220	2,867	2,359	3,628[a]	2,440[a]	3,538
	2015–16	3,467	3,242	3,599	3,881	3,653	3,543	4,002[a]	3,829[a]
Benefit–cost ratio	2014–15	2.03	1.08	2.27	1.95	2.58	2.53[a]	4.15[a]	2.43
	2015–16	2.15	1.73	2.23	2.63[a]	2.33	2.32	2.97[a]	2.46
Irrigation time (h/ha)	2014–15	13.75	46	13.75	45	13.75	41[a]	13.34[a]	43
	2015–16	15	86	15	74	12.5[a]	70	12.5[a]	69[a]
Labour productivity (A$/ha)	2014–15	4.22	2.87	4.46	4.18	7.70	8.02[a]	10.63[a]	7.79
	2015–16	4.57	5.04	6.00	7.08	4.73	8.87	6.41[a]	9.25[a]

A$ = Australian dollar; CTL = conventional tilled lentil; CTTPR = conventional tilled transplanted rice; MB = mungbean; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTL = zero-tilled lentil

a Best value for each district, indicating which treatment was best.

In Cooch Behar, the percentage increase in yield was highest for UPTPR-ZTL (32%) and lowest for CTTPR-ZTL (20%). However, the percentage increase in net profit was highest for CTTPR-CTL (70%) and so was the benefit–cost ratio (6%).

The cost of production rose in 2015–16. UPTPR-ZTL had the highest percentage increase in production cost (87%) so, although the gross return rise was highest (70%), net profit increased by just 64% and the benefit–cost ratio decreased by 28%. This was due to increases in labour cost, which may have been for manual weeding.

CTTPR-ZTL had the lowest increase in production cost (by 44%), with a 62% increase in net profit. The increase in net profit was wiped out by the increase in cost of production, so the benefit–cost ratio decreased by 2% in 2015–16 for this system. The time required for irrigation increased by 9% for CTTPR-CTL and CTTPR-ZTL, and decreased for ZTDSR-ZTL and UPTPR-ZTL by 9% and 6%, respectively.

In Malda, the highest percentage increase in yield was for CTTPR-ZTL-MB (11%); yield decreased for ZTDSR-ZTL-MB by 2%. But, production cost for CTTPR-ZTL-MB fell by only 0.1%; for two other treatments it increased, with the highest percentage increase for ZTDSR-ZTL-MB (by 24%), which reduced net profit 2% compared with 2014–15. CTTPR-CTL-MB had the highest percentage increase in net profit (by 39%) and the highest increase in benefit–cost ratio (by 60%).

For ZTDSR-ZTL-MB, the benefit–cost ratio fell by 8%; the other treatments had positive benefit–cost ratios. The percentage increase in labour productivity was highest for the CTTPR-CTL-MB system (76%) and lowest for ZTDSR-ZTL-MB.

Table 5.14 presents the results for the rice–mustard–maize system for 2014–15 and 2015–16 in Malda under different tillage practices, including conventional tilled mustard (CTM). Yield increased for all systems in 2015–16 compared with 2014–15. The highest percentage increase in yield was for the UPTPR-ZTMU-ZTM system (11%) and the lowest for CTTPR-ZTMU-ZTM (3%).

The percentage reduction in cost of production was highest for CTTPR-CTMU-CTM (18%), which resulted in the highest percentage increase in net profit (52%) and benefit–cost ratio (84%). This could be due to the high labour productivity. The cost of production increased by 1% in 2015–16 for the ZTDSR-ZTMU-ZTM system, which resulted in the lowest percentage increase in net profit (24%) and benefit–cost ratio (30%). This could be because of the lowest labour productivity (8%) and longest time required for irrigation.

Conclusion

The wage difference was highest in Dhanusha and lowest in Madhubani. Irrigation cost was highest in Madubani and lowest in Nepal due to subsidised diesel prices. The border effect on machinery used for land preparation can be seen in all SRFSI regions—for instance, for Aman rice, rotavators and rice transplanters were used in both Rajshahi and Malda. In Dhanusha and Madhubani, tractors were used to prepare the plots. The machinery hiring charge was higher in Rajshahi than in Rangpur. As in Bangladesh, there were differences in machinery hiring rates in Bihar, West Bengal and Nepal.

The cropping system was more diverse in Rangpur, Bangladesh, which included jute; in Purnea, Bihar, which included maize; in Malda, West Bengal, which included mustard, lentil and mungbean; and in Sunsari, Nepal, which included maize.

The year 2015–16 was not normal. There was a drought in the beginning of the season, rain during crop maturity and

Table 5.14 Productivity, profitability, irrigation time required and labour productivity for the rice–mustard–maize system under different tillage options in Malda, 2014–15 and 2015–16

Variable	Year	CTTPR-CTMU-CTM	CTTPR-ZTMU-ZTM	ZTDSR-ZTMU-ZTM	UPTPR-ZTMU-ZTM
Grain yield (t/ha)	2014–15	11.92	12.17	12.54[a]	11.79
	2015–16	12.37	12.51	13.34[a]	13.03
Biomass (t/ha)	2014–15	36.79	37.08	37.54[a]	37.13
	2015–16	39.53	39.60	40.23	41.20[a]
Production cost (A$/ha)	2014–15	2,712	2,090	1,914	1,897[a]
	2015–16	2,221	1,734[a]	1,939	1,748
Gross return (A$/ha)	2014–15	5,037	5,131	5,261[a]	5,052
	2015–16	5,750	5,880	6,100[a]	6,086
Net profit (A$/ha)	2014–15	2,326	3,041	3,346[a]	3,155
	2015–16	3,529	4,146	4,160	4,339[a]
Benefit–cost ratio	2014–15	0.83	1.47	1.79[a]	1.63
	2015–16	1.53	2.69	2.33	2.79[a]
Irrigation time (h/ha)	2014–15	211	173	169[a]	172
	2015–16	96	87	82[a]	82[a]
Labour productivity (A$/ha)	2014–15	2.87	4.18	8.02[a]	7.79
	2015–16	4.33	6.68	8.66[a]	8.64

A$ = Australian dollar; CTM = conventional tilled maize; CTMU = conventional tilled mustard; CTTPR = conventional tilled transplanted rice; UPTPR = unpuddled transplanted rice; ZTDSR = zero-tilled direct-seeded rice; ZTM = zero-tilled maize; ZTMU = zero-tilled mustard

a Best value for each district, indicating which treatment was best.

then storms. Thus, yields in 2015–16 were down from 2014–15 levels in Purnea for the rice–wheat system, in Bangladesh for the rice–wheat and rice–mungbean systems, in Sunsari for the rice–maize system, in Dhanusha for the rice–lentil system and in Cooch Behar for the rice–wheat system for all treatments. However, any practice with CASI has done relatively well compared with conventional practice, except for ZTDSR-ZTL-MB in Malda. We can conclude that CASI practices are more resilient, and in bad years yield loss is less than for conventional systems.

6 Farmer typologies for the Eastern Gangetic Plains

The purpose of developing typologies is to understand the diversity of household circumstances, and to group households with similar capacity and options to change their livelihood activities. Understanding farmer typologies also allows us to place agricultural adaptation options within the broader context of household livelihoods, and to understand household resource endowment, perceived risks and livelihood strategies.

This is relevant for the Sustainable and Resilient Farming Systems Intensification (SRFSI) project, particularly when designing interventions for farmers and for considering future scenarios. The basic question is what type of technology is suitable for which types of farmers and how can we improve its adoption? We can look at conservation agriculture (CA) technologies (such as zero-till machines and direct-seeded rice) as well as sustainable intensification (SI), which includes new crop types, rotations and cropping systems.

There have been two recent attempts to build farmer typologies across the Eastern Gangetic Plains.

Williams et al. (2016) built farmer typologies for India (Telangana state), Bangladesh, Cambodia and Laos using a range of methods, such as in-depth interviews on adaptive capacity, self-assessment workshops, household surveys, life history narratives (India only), participatory rural appraisal process, expert workshops and focus groups (farmer feedback on adaptation options). Williams et al. (2016) typologies for Telangana state were:

1. landless wage labourers from scheduled castes or backwards castes (BC)[1]
2. marginal and small farmers (less than 2 ha) with poor soil, and limited or no access to irrigation
3. marginal and small farmers with other productive assets, access to irrigation and varied soil quality
4. marginal and small 'other caste' (OC) farmers with good access to irrigation
5. medium and large farmers with no or limited access to irrigation
6. medium and large farmers with other productive assets
7. medium and large BC/OC farmers with good access to irrigation and good-quality soil.

Williams et al. (2016) typologies for Khulna, Bangladesh, district were:

- advantaged households (2 ha)
  - affected by moderate salinity, well connected to a regional centre
  - affected by high salinity, poorly connected to a regional centre
- medium households (0.5 ha)
- poor households (0.2 ha)
- landless households.

1 Scheduled castes, backward castes and other castes are government designations used to provide benefits to historically disadvantaged groups.

Sugden (2017) has also been building farmer typologies in India and Nepal (see Table 6.1).

Approach

Given these previous attempts, can we build a simplified typology based on a mix of the Williams and Sugden typologies that will be relevant for the SRFSI project? We wish to build on Sugden's typology and incorporate other factors to encompass a range of attributes that might contribute to our understanding of issues faced by farmers and households and—ultimately—what might influence adoption of conservation agriculture–based sustainable intensification.

Table 6.2 shows the suggested framework (the 22 categories are fully detailed in the Appendix). This table is not complete, but we want to provide a sense of the type of information we have available. The framework can then be finalised, and identify gaps or re-emphasis any aspects of the framework. We note that gender is not yet considered in the draft framework.

The broad categories for consideration are (see the Appendix):

- farmer land ownership category
- tenure
- land ownership
- food security
- axes of exploitation
- labour relations
- technology access (pump sets, tractors, thresh, etc.)
- gender and demographics
- cash income
- livestock (number and size)
- caste position (if relevant)
- land characteristics (fertility)
- on-farm income (%)
- off-farm income (%)
- credit access (availability and timeliness)
- irrigation (area or type of irrigation)
- percentage engaged in farm labour
- percentage engaged in off-farm labour
- percentage of households in category
- percentage total land owned by sample belonging to each group
- prospects for CA equipment
- prospects for SI.

It was proposed to explore this typology framework among the SRFSI socioeconomic team, then seek more comments and input from the broader SRFSI project team. It was presented at several SRFSI annual planning meetings and received broad support.

How this framework could be used

This typology framework can be used to ask some key questions to help with understanding issues about CA technologies and SI, and adoption:

- What CA technologies are appropriate for which farmer typologies?
- Do we want to focus on maximising area under CA and SI, or numbers of households under CA and SI?
- What opportunities are there for landless, tenant and marginal farmers?
- What impact will CA or SI have on gender issues? How will this affect percentage of time allocated to various tasks (e.g. household chores, time spent in the field, caring for livestock)?
- Can we identify broad issues that we need to think about for adoption of CA and SI? What likely barriers exist, and how can we build on enablers?
- What impact does access to irrigation have on adopting CA and SI?

Table 6.1 Typologies for Nepal and India

Broad category	Tenure	Land ownership	Food security	Axes of exploitation	Labour relations	Technology access (pump sets, tractors, thresh, etc.)	Gender and demographics	Cash income
Small farmer	Tenant or part tenant	<50% of cultivated land rented	Grain deficit	• Rent given to others • Interest on loans paid to others	Labours for others	Rents equipment	High male out-migration, feminisation of production	• Migrant labour • Distress sales
	Marginal owner cultivator	<0.5 ha	Grain deficit	• Interest on loans paid to others	Labours for others	Rents equipment	High male out-migration, feminisation of production	• Migrant labour • Distress sales
Medium farmer	Medium owner cultivator	0.5–2 ha	Subsistence level	• Interest on loans paid to others	Labours on own farm only	Rents and owns equipment	High male out-migration, feminisation of production	• Migrant labour • Some commercial sales
Large farmer	Large owner cultivator	>2 ha	Produces surplus	• Rent received from others • Interest on loans received from others	Buys labour of others	Owns and rents out equipment to others	Lower levels of male out-migration, less dependence on household labour	• Commercial produce sales • Skilled/ professional labour

Source: Sugden (2017)

Table 6.2 Suggested typologies for SRFSI to enable and support CASI

Broad category	Farmer land ownership category	Tenure	Land ownership	Prospects for CA equipment	Prospects for SI
Landless labourer	Landless labourer	Landless	None	None[a]	None
Tenant	Tenant	Tenant	<50% of land rented	Low[a]	Some (new crops)
Part tenant	Part tenant	Part tenant	<50% of land rented	Low[a]	Some (new crops)
Marginal farmer	<0.5 ha	Marginal owner cultivator	<0.5 ha	Low–moderate	New crops and rotations
Small farmer	0.5–1 ha	Small owner cultivator	0.5–1 ha	Low–moderate	New crops and rotations
Medium farmer	1–2 ha	Medium owner cultivator	1–2 ha	High	New crops and rotations
Large farmer	>2 ha	Large owner; rents out surplus land	>2 ha	High	New crops and rotations

CA = conservation agriculture; SI = sustainable intensification

a Although landless and tenant farmers do not have access to much land, there are opportunities to become machinery owners or tractor drivers.

7 Mechanisation: services and subsidies

Conservation agriculture–based sustainable intensification (CASI) mechanisation results in:

- faster, more precise agricultural operations
- higher field coverage over a short period
- cost-effectiveness
- efficiency in use of resources and applied inputs
- conservation of available soil moisture under stress conditions
- adequate drainage of excess rain and floodwaters.

Across Sustainable and Resilient Farming Systems Intensification (SRFSI) sites, farmers are deeply interested in timely and affordable access to conservation agriculture (CA) machinery to reduce labour and water costs.

Bangladesh is the most mechanised of the jurisdictions, which was achieved when cheap Chinese two-wheeled tractors were imported under conditions of economic liberalisation in the 1990s. Since the mid 1990s, research and development work on CA-based resource conservation technologies started with locally developed small machinery (such as minimum and zero-tillage planters), crop production on permanent bed systems and residue retention. During this time, national capacity for producing spare parts for Chinese machinery increased. Since 1995, the Bangladesh Agriculture Research Institute, the Bangladesh Rice Research Institute and the International Maize and Wheat Improvement Center collaborated with national agriculture research systems, non-government organisations, the private sector and farmers throughout the country, with funding from various donors, particularly USAID (Miah et al. 2009).

In contrast, Nepal's long and porous land border with India, and lack of a port to ease imports from China, means that India's preference for four-wheeled tractors and attachments is influencing Nepal's pattern of farm mechanisation more than Bangladesh's.

Mechanisation in Nepal

Farm machinery—mostly confined to the Terai region—currently provides 23.2% of Nepal's farm power. Use of animal and human power remains dominant. Rotavators are widely used in the eastern Terai, although continuous use can damage the soil. Four-wheeled tractors are commonly used for tillage and transportation operations, with SRFSI smallholder farmers having difficulty accessing them for zero-till operations (Darbas 2017). Training, provided to tractor operators/owners and farmers by the District Agriculture Development Office, has not motivated service provision and no equipment hire hubs have been developed.

The SRFSI farmers are using zero-tillage seed drills for direct-seeded rice in the Kharif season; for wheat, kidney beans, lentil, maize in the Rabi season; and for mungbean in the spring season. Rice transplanters and laser land levellers are also being tested. The machines are provided through Nepal Agricultural Research Council's Dhanusha and Sunsari district research stations. Although the participating farmers were initially reluctant to use zero-tillage seed drill technologies, there is now growing demand for access to this technology where it can be used.

Small diesel-powered pump used to irrigate fields before planting crops, Bhagalpur, Bihar, India, 2012. Photo: Peter Brown, CSIRO

Kuber and Sons Trade Link in Itahari, Sunsari district, was contracted by iDE Nepal to provide field demonstrations of zero-tillage seed drills and related technologies to the farmers. This helped Kuber and Sons to sell 30 zero-tillage seed drill machines nationally, including in Sunsari district. The company provides maintenance and repair services, initially through the support of iDE Nepal. The District Agriculture Development Office in Sunsari district provided a 75% subsidy for anyone who purchased a zero-tillage seed drill machine in 2015 and 2016. However, the 50% subsidy for power tillers has more uptake.

Conservation agriculture–based sustainable intensification machinery in Bangladesh

Two-wheeled tractors have a long history in Bangladesh, and 60–70% of the net cultivable land is tilled with this machine. There are two models—Dongfeng and Sifang—and both are imported from China. Farmers of all SRFSI nodes frequently rely on two-wheeled tractors. To introduce minimum tillage, Bangladesh Agriculture Research Institute scientists collaborated with the International Maize and Wheat Improvement Center to increase use of two-wheeled tractors, because:

- credit purchase options are widely available
- sales trends show steady growth
- repair services and spare parts (local and imported) are widely available (although standards remain variable)
- the return on investment for two-wheeled tractors is attractive
- they are versatile and can be used for rural transport.

Bangladesh also has a long history of four-wheeled tractor use, with most in the 27–90 horsepower (hp) range. The 27–41 hp tractors are used for haulage and higher horsepower tractors are used for both tillage and haulage. It is noted that 12–16 hp are two-wheeled driven and the 75–90 hp tractors are four-wheeled driven machines. Tilling is undertaken with either rotovator or cultivator attachments; a cultivator attachment with 9–11 tines can till to a depth of 23 cm.

The four-wheeled tractors are largely imported from India through Benapol land port. Currently, four-wheeled tractor services are expanding in the eastern, western and southern belts of Bangladesh. The larger tractors are being successfully used to cultivate small plots of land, and the tilling cost is lower than for two-wheeled tractors. Key factors explaining this rapid expansion in four-wheeled tractor use are:

- sales have been boosted through installment payment options (although advertised instalment calculations are misleading)
- network marketing is a major driver of sales
- after sales services are available to safeguard investments
- four-wheeled tractors owners' associations are emerging
- the Bangladesh Government launched a subsidy-based four-wheeled tractor sale program to farmers
- a second-hand rotovator market has emerged.

The focus groups indicated that about 85% of landholdings are in the small and marginal category, with households enjoying minimal capital and an average land size of 0.45–0.71 ha. If they rely on machinery, it is usually two-wheeled tractors for tillage, although the use of four-wheeled tractors is increasing. Power tillers and tractors are used for around 80% of the land preparation. Powered multicrop threshers and shellers are widely used for paddy, wheat and almost all maize (around 80%). Currently, paddy, wheat and maize harvesting is not mechanised. The SRFSI project has introduced seeders with strip tillage and bed planting for maize, wheat, paddy, jute and mustard, and for jute cultivation. Labour shortages during planting and harvesting critically hamper crop profitability, which drives adoption of paddy and wheat reaper machines. There are very few combine harvesters and laser land levellers available, and they are needed in all nodes.

Small diesel-powered pump used to irrigate wheat fields, Dhanusha, Nepal Terai, 2015.
Photo: Peter Brown, CSIRO

8 Policy implications

Water–energy–food trade-offs and synergies

Hoff (2011) first defined the nexus between the water–energy–food (WEF) sectors. WEF analysis is intended to support the management of trade-offs (i.e. conflicts), and achieve synergies between the WEF sectors. WEF thinking developed from integrated water resource management ideologies, which is why WEF has continued to place water resources at the centre of analysis. Rasul (2016) explains that nexus thinking attempts to prevent a crisis in one sector being shifted to another sector, due to the unintended consequence of policies. Such a displacement occurred in the Indian state of Punjab when highly subsidised rural electricity was provided to encourage Rabi season cropping with groundwater. This policy setting undermined the economic viability of electricity provision and permitted the unsustainable mining of groundwater, while farmer 'vote banks' to protect the subsidy have become entrenched (Shah, Giordano & Mukherji 2012).

Achievement of WEF trade-offs and synergies relies on two strategies: quantitative system analysis to develop shared datasets that can support improved decision-making and improved WEF governance. The latter strategy is less developed, although ultimately, tensions between the three sectors need to be resolved at the local level. This presents a horizontal coordination challenge between sectors and a vertical coordination challenge between levels of government (Scott 2017). Former minister of Energy, Water Resources and Irrigation (Nepal), Radha Gyawali, argues that negotiating nexus solutions, such as investment in a multipurpose dam, also requires the private sector (e.g. banks, energy suppliers, irrigators) and civic sector (e.g. rural development non-government organisations [NGOs]) stakeholder to be engaged (Gyawali 2015).

The WEF challenge facing the Easter Gangetic Plains (EGP) is how to increase food production while decoupling it from water and energy-use intensity (Rasul 2016). This challenge has been effectively addressed in Bangladesh by the Barind Multipurpose Development Agency, originally established as a project in 1985 in the 15 upzillas of the Barind Tract. Since 1985, the agency has developed a network of 5,000 deep tube wells to bring 400,000 acres of land under Rabi cropping. This development has been sustained by:

- lining canals and pipes to gain water distribution efficiency of 70–80%
- ensuring a sustainable yield through groundwater-level monitoring
- reviving the tradition of excavating and maintaining tanks to recharge aquifers
- recovering 100% of operating and maintenance costs,

including salaries, through water and power charges
- constructing 110 km of feeder roads, power lines and substations
- establishing nurseries and undertaking reforestation
- integrating with local rural development NGOs
- providing a training shed and workshops for farmers
- promoting organic fertiliser and pest control
- a seed collection and distribution program (Faisal, Parveen & Kabir 2005).

Assuming that further surface-water development is unlikely in the EGP, WEF synergies can be pursued by tightening efficiencies in water and energy use while closing yield gaps and supporting cropping intensification. These efficiencies depend on user-pay settings for energy and water, and could involve:

- replacing regular pumps with more energy-efficient or solar pumps
- increasing 'crop per drop', and using a less thirsty third crop in the rice–rice and rice–wheat systems
- promoting affordable laser land levelling services to increase water use efficiency
- improving the energy efficiency and efficient use (e.g. single pass) of conservation agriculture (CA) machinery.

It is important to explore options through which farmers can achieve more crop with less water. These include planting drought-resistant crops or vegetables, building on farmers' indigenous knowledge, and refining more technology-heavy interventions such as zero tillage and other CA techniques such as laser levelling.

Mechanisation: access, affordability and efficiencies

Policymakers have prioritised improving the performance of Nepal's agriculture sector to achieve food security, employment and economic growth. However, Nepal's 2016 Agricultural Mechanization Subsidy Operational Directives (1st amendment 2017), while providing a 50% subsidy on most machines and attachments, favours large farmers despite most farmers only holding an average of 0.68 ha. Individuals must own a minimum of 1.5 ha, 0.5 ha and 0.25 ha in the Terai, the mid-hills and the mountains, respectively. Groups must hold a total of 4 ha in the Terai, 1.5 ha in the mid-hills and 0.5 ha in the mountains. To access a subsidy on large machines such as a four-wheeled tractor, laser land leveller or combine harvester, an individual must own 5 ha of land and a group 10 ha. They must also purchase attachments costing Rs0.5 million. The machinery is mostly imported from India and its suitability for Nepal's diverse agroecology and socioeconomic settings is questionable. The need to identify, develop and promote appropriate machinery and service provision mechanisms in Nepal remains.

The Government of Bangladesh subsidises 25–60% of the price of agricultural machines. However, farmers have become interested in multiple crop planters and seeders, rice transplanters and harvesters. Further subsidies to purchase, and more work to improve the performance of multicrop planters and crop harvesters would speed up mechanisation. A group approach is needed for subsidies to small and marginal farmers, and it is also important to develop local manufacturing workshops and industries. Public, NGO and private sector collaborations and partnerships are vital for farm mechanisation in this region. The government has acknowledged the importance of agricultural mechanisation in the National Agricultural Policy, which states that 'the Government will encourage production and manufacturing of agricultural machinery adaptive to our socioeconomic context. Manufacturing workshops and industries engaged in agricultural mechanisation activities will be provided with appropriate support' (Bangladesh Ministry of Agriculture 1999).

Another way Bangladesh could increase agricultural mechanisation is by using more precise seed and fertiliser attachments. This could facilitate new agronomic practices, such as placing seed and fertiliser together in the same furrow, to increase the efficiency of fertiliser uptake by 10–15% and result in more uniform plant stands. There are several seeder attachments currently on the market. Power tiller-operated seeders are a potential two-wheeled tractor attachment for seed drilling that can simultaneously till, sow and perform laddering operations in a single pass, and can be used for various crops. With current versions, most seed (e.g. wheat, paddy, maize, jute, pulses, oilseeds) can be sown in line. Power tiller-operated seeder owners earn cash income by hiring to other farmers for tillage. Adoption is poor considering the machine's potential, although in some areas this machine is used for establishing onions.

The machinery hire hub models developed in the West Bengal and Bangladeshi innovation platforms could be used for ensuring that resource-poor farmers can access conservation agriculture–based sustainable intensification (CASI) machinery.

Market and private sector engagement: access, affordability, efficiencies

Future market research could analyse the costs that poor infrastructure poses, such as poor roads, electricity access, marketyards and access to loans. Evidence from desktop studies, and as primary and secondary data could be used to influence policymakers to prioritise investments in the physical and financial infrastructure, to reduce the connectivity costs for farmers and companies.

Currently, large private companies are not interested in investing in the region. In India, government requires private companies to spend 1% of their profits on corporate social responsibility (CSR) projects. Efforts to mobilise CSR funds for sustainable investment in agriculture have not succeeded either. Companies try to invest CSR funds in areas where they source their raw material from, or find, large markets. At present, the EGP region is not very attractive to them from either side. Therefore, the Sustainable Development Investment Portfolio (SDIP) will better target small and medium enterprises in the region. Some form of aggregation of inputs and produce is also needed to increase farmers' bargaining power in the market and reduce companies' cost of doing business with them. There are currently few functioning producer organisations in the region that could act as intermediaries between smallholders and agribusinesses. We need to better research design principles for replicating successful producer organisations, such as Purnea district's Aranyak Agri Producer Company, and build capacities in governments, NGOs and communities to form more such organisations.

The Sustainable and Resilient Farming Systems Intensification phase 1 project includes a vision for a business model for a farmer service company that will set-up rural business hubs to provide different inputs and services (e.g. seeds, fertilisers, agricultural equipment hiring, agricultural advice, credit and insurance) to farmers at one place. These outlets will act as one-stop shops for farmers. The idea is to exploit the economies of scope in an area where any one activity cannot generate sizeable enough business to attract a large private investor. However, the International Food Policy Research Institute's study on rural business hubs that are set-up by a private company in central and eastern Uttar Pradesh shows that such one-stop shops are unlikely to become viable in areas with low levels of agricultural development. The lessons from Uttar Pradesh should be kept in mind while trying this business model in the EGP region during phase 2 of the SDIP.

Increasing productivity is essential to reduce cost of production and to generate enough marketable surplus at the local or regional level. If yields are low and subsistence agriculture is the dominant mode of production, there will be no private investment even if infrastructure improves. Madhubani in Bihar is a case in point. Therefore, research and extension efforts to increase crop productivity should continue in such areas.

9 Significance for the Eastern Gangetic Plains

Scaling-out strategies

The most important outcome of the multistakeholder forums or innovation platforms (IPs) is the emergence of several business models. This is particularly true in the districts with more enabling institutional environments (Cooch Behar, Malda, Rangpur–Dinajpur, Rajshahi and Purnea) that are—or could become—economically self-sustaining. They could also help to extend conservation agriculture–based sustainable intensification (CASI) (see Chapter 3). Of these models, village-based input shops and CASI equipment hire are the most prominent (Table 9.1).

In contrast to these successful village-based IPs, district-level IPs have failed to take root for lack of engagement by busy stakeholders. Neither have they re-animated multilevel agricultural stakeholder forums that already exist but fail to function in both India and Nepal.

Scaling-up strategies

The best model here is the West Bengal farmer clubs' access to National Bank for Agriculture and Rural Development credit to purchase CASI equipment as a group. The bank uses group assets and effective group governance as a criteria for borrowing. This forms a strong contrast to the difficulty obtaining group-based credit for shallow tube wells or farm machinery in Nepal, which relies only on group assets (i.e. land ownership) as a criteria. Across the Eastern Gangetic Plains (EGP), feudal exploitation of the vulnerable, rent-seeking (e.g. overpricing shallow tube well irrigation) and program leakage endure and prevent the capitalisation of smallholder agricultural production. Good group governance promotes accountability, fairness and trust. Group-based subsidy and credit provision methodologies need to depend on good group governance.

Group methodologies make capacity building for smallholders feasible. It also aids partnership between public agencies, such as Bangladesh's Department of Agricultural Extension, and effective rural development NGOs, such as Bihar's JEEViKA and Rangpur's RDRS. These partnerships are mutually helpful for fulfilling organisational mandates. Up-front investment in capacity building can deliver new frontline extension services, as shown by the outreach achieved by farmer clubs and groups in West Bengal and Bangladesh. West Bengal's Department of Agriculture and Bangladesh's Department of Agricultural Extension are using well-governed farmers clubs as frontline extension services, to make more strategic use of their limited number of extension officers. As an example, to deal with pest and disease outbreaks before they spread.

Table 9.1 Conservation agriculture–based sustainable intensification (CASI) business models, 2017

Business model	Location	Features
Seed production groups	• Bhokraha, Sunsari (wheat) • Sinurjoda, Dhanusha (forage) • Kalinagar node, Malda (lentil) • Manikchak FC, Malda (wheat)	• MOUs with agribusinesses • Local distribution • Supply of extension agencies • Quality control and certification • Method of encouraging switch to higher yielding and shorter duration varieties
CASI equipment hire hub in 13 nodes	• All Rajshahi district nodes • All Rangpur district nodes • Satmile Satish and Sabuj Mitra FCs, Cooch Behar • Kalinagar node, Malda	• In-house equipment • Repair/service workshop, and driver immune from haulage/transport competition in peak periods • Registered club/NGO access to institutional credit and equipment subsidies in West Bengal CBF
Maize marketing company	• Purani Garel node, Purnea	• Leverage women's SHG-based capacity-building program • Electronic scales and moisture readers • Marketing SMS messaging • Aggregation of produce • Storage in accredited warehouse • Post-harvest glut sales to institutional buyers • Electronic payment • Bonus payment
Maize subcontract	• Sabuj Mitra FC, Cooch Behar	• Crop establishment and care for 50 days inclusive of all inputs • Aggregation of input demand • CBF
Village-based input shops in 5 nodes	• All Purnea nodes	• MOUs with agribusinesses • Village-based entrepreneur • Aggregation of input demand
Agricultural clinic or input shop	• All Rangpur nodes	• DAE provides pest and disease advice • Aggregation of input demand • Agribusiness product demonstration • Capacity building • Some credit provision
Convergence with flagship programs	• All Cooch Behar nodes	• FCs run demonstrations of high-yielding varieties and CA equipment on behalf of DoA for the Bringing the Green Revolution to Eastern India and National Food Security Mission on Pulse programs

CA = conservation agriculture; CBF = community business facilitator; DAE = Department of Agricultural Extension; DoA = Department of Agriculture; FC = farmer cooperative; MOU = memorandum of understanding; NGO = non-government organisation; SHG = self-help group

Improving access to, and the affordability of, irrigation is necessary to boost agricultural production. 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.

EGP jurisdictions could support female cultivators by reducing or de-emphasising the current gendered segregation of the livelihood strategies typically pursued by self-help groups (e.g. for livestock, beekeeping, fisheries) and farmer groups and clubs (e.g. for food grain production, CASI services). Such program de-segregation could be tested as a long-term transformational strategy for prevailing gender relations across the EGP, given the male labour out-migration and the feminisation of agriculture. As shown by the success of the Aranyak Agri Producer Company, partnerships with women-centric NGOs to provide services insitu to bypass the mobility constraints on women cultivators are a proven method that could be extended through financially sustainable business models.

Limiting rice procurement in the Punjab–Haryana belt and encouraging it in Bihar and West Bengal where groundwater has not (yet) reached unsustainable use levels is a policy option available in India.

Appendix

Tables A1.1–A1.3 show the details for the 22 variables for the suggested farmer typologies for the Sustainable and Resilient Farming Systems Intensification project in the Eastern Gangetic Plains. The variables ‘broad category’ and ‘farmer land ownership category’ are repeated in each table to facilitate readability.

Table A1.1 Suggested typologies for Sustainable and Resilient Farming Systems Intensification farmers—land variables

Broad category	Farmer land ownership category	Tenure	Land ownership	Households in category (%)	Total land owned by sample in group (%)	Land characteristics (fertility)	Irrigation (area or type of irrigation)	Food security	Technology access (pump sets, tractors, thresh etc.)
Landless labourer	Landless labourer	Landless	None	22.7	0.4	Not applicable	Not applicable	Grain deficit	Rents equipment
Tenant	Tenant	Tenant	<50% of cultivated land rented	14.3	0.2	Low	Rainfed/ rented	Grain deficit	Rents equipment
Part tenant	Part tenant	Part tenant	<50% of cultivated land rented	14.7	9.7	Low	Rainfed/ rented	Grain deficit	Rents equipment
Marginal farmer	<0.5 ha	Marginal owner cultivator	<0.5 ha	18.3	9.0	Medium	Rainfed/ rented	Grain deficit	Rents equipment
Small farmer	0.5–1 ha	Small owner cultivator	0.5–1 ha	12.3	16.2	Medium	Rainfed/ rented	Subsistence level	Rents and owns equipment
Medium farmer	1–2 ha	Medium owner cultivator	1–2 ha	11.6	29.1	High	Owned	Subsistence level	Rents and owns equipment
Large farmer	>2 ha	Large owner cultivator. Rents out surplus land	>2 ha	5.5	35.5	High	Owned	Produces surplus	Owns and rents out equipment to others

Table A1.2 Suggested typologies for Sustainable and Resilient Farming Systems Intensification farmers—demographic variables

Broad category	Farmer land ownership category	Gender and demographics	Labour relations	Engaged in farm labour (%)	Engaged in off-farm labour (%)	Cash income	Caste position (if relevant)
Landless labourer	Landless labourer	High male out-migration, feminisation of production	Labours for others	31.9	32.6	• Migrant labour • Distress sales	SC/BC wage labourers
Tenant	Tenant	High male out-migration, feminisation of production	Labours for others	33.9	29.4	• Migrant labour • Distress sales	SC/BC wage labourers
Part tenant	Part tenant	High male out-migration, feminisation of production	Labours for others	24.7	20.9	• Migrant labour • Distress sales	SC/BC wage labourers
Marginal farmer	<0.5 ha	High male out-migration, feminisation of production	Labours for others	20.4	17.3	• Migrant labour • Distress sales	Various
Small farmer	0.5–1 ha	High male out-migration, feminisation of production	Labours on own farm only	9.2	14.5	• Migrant labour • Some commercial sales	Various
Medium farmer	1–2 ha	High male out-migration, feminisation of production	Labours on own farm only	7.0	11.2	• Migrant labour • Some commercial sales	BC/OC
Large farmer	>2 ha	Lower levels of male out-migration, less dependence on household labour	Buys labour of others	11.6	10.1	• Commercial sales of produce • Skilled/ professional labour	General

BC = backwards castes; OC =other castes; SC = scheduled castes

Table A1.3 Suggested typologies for Sustainable and Resilient Farming Systems Intensification farmers—monetary and other variables

Broad category	Farmer land ownership category	Axes of exploitation	On-farm income (%)	Off-farm income (%)	Credit access (available and timely)	Prospects for CA equipment	Prospects for SI
Landless labourer	Landless labourer	• Rent given to others • Interest on loans paid to others	0	100	Informal source, high interest rate	None	None
Tenant	Tenant	• Rent given to others • Interest on loans paid to others	38	52		Low	Some (new crops)
Part tenant	Part tenant	• Interest on loans paid to others	40	60		Low	Some (new crops)
Marginal farmer	<0.5 ha	• Interest on loans paid to others	72	28		Low/moderate	New crops and rotations
Small farmer	0.5–1 ha	• Interest on loans paid to others	72	28		Low/moderate	New crops and rotations
Medium farmer	1–2 ha	• Interest on loans paid to others	72	28		High	New crops and rotations
Large farmer	>2 ha	• Rent received from others • Interest on loans received from others	72	28	Formal, low interest rate	High	New crops and rotations

CA = conservation agriculture; SI = sustainable intensification

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