Chapter 22
Socioeconomic Impacts of Conservation Agriculture based Sustainable Intensification (CASI) with Particular Reference to South Asia

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Abstract Compared to the past successes of global food supply, reduced natural and social capitals, Food-Energy-Water insecurities, climate change and volatile international commodity markets threaten future food production. Among the options for sustainable agriculture, various No-till (NT) practices have been adapted to different farming systems around the world. One particular adaptation, Conservation Agriculture based Sustainable Intensification (CASI) that combines the strengths of conservation agriculture and sustainable intensification, has succeeded in a number of farming systems including parts of South Asia. Farmer-participatory on-farm research results in the irrigated Rice-Wheat Farming System of Bangladesh, eastern India and Nepal showed that CASI strengthened the Food-Energy-Water nexus through increased food crop productivity, and energy and water use efficiencies. Furthermore, CASI reduced greenhouse gas emissions and improved natural resources. Notable socioeconomic impacts of CASI were improved household food security and income, reduced production costs, better

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returns to labor, benefits to women, expanded social capital and strengthened system resilience. These socioeconomic benefits are important drivers of smallholder adoption of CASI and underpin the prospects for widespread scaling. These impacts from South Asia are an example of the potential for CASI adaptation for other irrigated and dryland farming systems elsewhere in South Asia, as well as in East Asia, the Middle East and Africa.

Keywords Farming systems intensification · Natural resource management · Risk · Gender · Innovation systems · Scaling up · South Asia

22.1 Introduction

The projected growth of global population and consumer purchasing power points to the need for greatly increased food production by mid-Century. The historic growth of food supply over the past 60 years was essential to meet the expanding demand for food, reduce hunger and avert famines. However, the intensification of agriculture resulted in substantial environmental costs, including depleted aquifers, degraded land and reduced resilience (Beddington et al. 2012; Paroda 2018). Considering the expected surge in demand for food by 2050, strengthening the underlying Food-Energy-Water nexus is an essential foundation for the sustainable intensification of agriculture to meet food demand while conserving, or ideally enhancing, natural resources and adapting to climate change (Shah et al. 2012; FAO 2014, 2016).

No-till (NT) cropping is a promising approach to sustainable food systems. One adaptation of NT practices is Conservation Agriculture based Sustainable Intensification (CASI) that embodies the strengths of conservation agriculture and sustainable intensification. Conservation agriculture is an agroecosystem approach distinguished by three well-known principles, viz, NT, maintenance of a permanent soil cover, often by stubble retention (SR), and diversification of crops, typically through rotation or inter-cropping (Hobbs 2007; Kassam et al. 2018) – with due regard to improved farm profit or livelihoods (Dixon 2003; Joshi et al. 2010). Sustainable intensification (SI) is a broad concept that emphasises concurrent improvements of agricultural productivity and environmental conditions (Godfray et al. 2010; Oborn et al. 2017). Pretty et al. (2018) defines SI as 'agricultural processes or systems in which production is maintained or increased while progressing toward substantial enhancement of environmental outcomes'. Generally, SI strengthens the Food-Energy-Water nexus, improves food and nutrition security, reduces rural poverty and promotes rural transformation (Grafton et al. 2016).

Typical intensification and conservation practices of CASI include NT, SR, on-farm diversification, planting of improved cultivars and management of nutrients, weeds and pests. The concept of CASI resonates with the food production-intensification and the environment-sustainability narratives and policies of many national and international organizations. The choices of CASI innovations depend on the specific farming system context and supporting institutions, including input and produce markets. Naturally, a systems approach to CASI facilitates R&D and accelerates impacts (Lal 2015; FAO 2016).

The socioeconomic impacts of CASI depend on a foundation of integrated Food-Energy-Water securities and functional pathways to adoption in order to generate environmentally, economically and socially efficient farming systems. Such adoption pathways of CASI innovations require effective policies and institutions. Farm households benefit from improved food security, increased net income (partly from savings in production costs), reduced labor requirements, increased returns to labor and reduced risks associated with production and marketing. The effects on Food-Energy-Water securities, especially the efficiencies of energy and water use, can be assessed using on-farm trial data. Household surveys and focus-group discussions underpin the estimation of farm household benefits and assessment of institutions for scaling, value chains, social capital and spillovers. Selected socioeconomic impacts from several CASI applications in the Rice-Wheat Farming System of South Asia – supported by South Asian National Agriculture Research Systems (NARS), the Australian Centre for International Agricultural Research (ACIAR) and the Australian Department of Foreign Affairs and Trade, among others – illustrate the magnitude of socioeconomic impacts from CASI more generally across South Asia and in other regions.

The South Asian Rice-Wheat Farming System is one of the major food bowls of the world and covers approximately 13 Mha of the Indo-Gangetic Plains in Bangladesh, India, Nepal and Pakistan (Dixon et al. 2001; Timsina and Connor 2001). The farming system has evolved since the Green Revolution, for example expanding rice areas in the western region and increasing wheat and maize areas in the eastern region (Erenstein et al. 2010). The eastern Rice-Wheat Farming System, and specifically the Eastern Gangetic Plains in Bangladesh, eastern India and Nepal, is a hotspot of food insecurity, poverty, resource degradation and severe climatic stress (Dixon et al. 2016). The Eastern Gangetic Plains contains more than 450 million inhabitants with a population density of approximately 1000 persons km^{-2}, and 68 million farm households, of whom more than 70% are marginal. Figure 22.1 illustrates six contrasting farming subsystem zones in the eastern region, which are characterized by different natural resources, cropping and livestock patterns, and availability of markets and machinery services (Tiwari et al. 2017). Such a classification is useful for targeting CASI innovations, understanding pathways to adoption and impact, and identifying scaling strategies and partners (Gathala et al. 2018a).

The foundation for CASI research in the region was established by the Rice-Wheat Consortium and subsequently strengthened by the Cereal Systems Initiative for South Asia and the Borlaug Institute for South Asia, as well as a variety of other research initiatives. The Sustainable and Resilient Farming Systems Intensification (SRFSI) Project conducted on-station and on-farm trials and surveys on CASI in the eastern region (Islam et al. 2019). The Happy Seeder Policy project investigated the value chains for the provision of NT planting services to combat, inter alia, rice straw burning (SB) (Loch et al. 2018). A meta-analysis of Happy Seeder NT planter

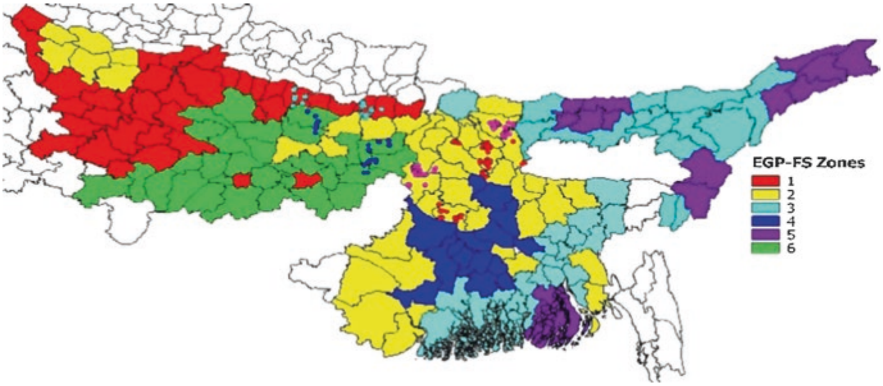

Fig. 22.1 Farming subsystem zones of the eastern Rice-Wheat Farming System. (Tiwari et al. 2017)

studies confirmed its viability as an alternative to rice SB in north-west India (Shyamsundar et al. 2019). The Farmer Behaviour Insights project is investigating another key issue, viz, farmer decision making on CASI adoption in the Eastern Gangetic Plains (Rola-Rubzen and Murray-Prior 2018).

The results of these research initiatives shed considerable light on the Food-Energy-Water nexus and socioeconomic impacts of CASI. The next section highlights the contributions of CASI to the Food-Energy-Water nexus, and Sect. 22.3 summarises farm household benefits including gender equity and risk reduction. In Sect. 22.4 the institutions for scaling CASI are discussed. Key lessons and conclusions outlined in the final Sect. 22.5.

22.2 Food-Energy-Water Nexus

Converging Food-Energy-Water insecurities are a major threat to food systems in South Asia (Shah et al. 2012). Globally, food crop intensification depends on the availability of energy and water (FAO 2014). The nature of the cropping system, including food and cash crop rotations and production technologies, influence the status of the Food-Energy-Water nexus, as illustrated by the following research on CASI in South Asia.

On-farm trials with double or triple cropped rice-based systems under CASI were conducted by the SRFSI Project with more than 400 farmers across the Eastern Gangetic Plains. Food production was evaluated under full and partial CASI practices (the latter with CASI except for kharif rice) against farmers' conventional practices including conventional tillage (CT) (Islam et al. 2019). The results showed that, for all cropping systems, food productivity was higher under CASI (averaged over partial and full practices) than with CT, whether measured in total annual food grain (in rice grain equivalents based on crop prices) or food energy (Table 22.1).

Table 22.1 CASI contributions to Food-Energy-Water by cropping system

System performance indicators	Cropping systems*	CT	CASI	Improvements CASI cf. CT (%)
System grain **yield** (Mg ha^{-1} year^{-1}) and food energy productivity (in parentheses, GJ ha^{-1} year^{-1})	RW	8.6 (304)	8.9 (315)	+3.2 (+4)
	RM	11.8 (520)	12.3 (541)	+3.9 (+4)
	RL	12.4 (261)	13.2 (269)	+5.9 (+3)
	RWMb	10.9 (408)	11.6 (408)	+6.2 (0)
	RWJ	13.8 (478)	14.2 (470)	+3.0 (−2)
System **energy** use (GJ ha^{-1} year^{-1}) and EUE (in parentheses, MJ MJ^{-1})	RW	30.0 (12)	27.0 (14)	−10.0 (+15)
	RM	35.3 (15)	32.9 (17)	−6.8 (+13)
	RL	20.0 (13)	18.3 (15)	−8.5 (+15)
	RWMb	40.7 (10)	36.4 (11)	−10.6 (+14)
	RWJ	34.7 (14)	32.8 (14)	−5.5 (+4)
System irrigation **water** use (ha-cm year^{-1})** and WUE (in parentheses, kg grain m^{-3} water)***	RW	20.8 (4.9)	18.2 (6.1)	−12.5 (+24)
	RM	23.1 (8.9)	20.3 (11.1)	−12.1 (+25)
	RL	– (0.50)	– (0.52)	– (+4)
	RWMb	– (0.71)	– (0.75)	– (+6)
	RWJ	– (0.63)	– (0.67)	– (+6)
System CO_2 equivalent emissions (Mg ha^{-1} year^{-1})	RW	1.55	1.36	−12
	RM	1.81	1.65	−9
	RL	1.00	0.90	−10
	RWMb	2.11	1.89	−10
	RWJ	1.71	1.26	−26

Source: Data from Gathala et al. (2018b) and Islam et al. (2019) recalculated and summarized.
Notes: **RW* Rice-wheat, *RM* Rice-maize, *RL* Rice-lentil, *RWMb* Rice-wheat-mungbean, *RWJ* Rice-wheat-jute; **Jute, lentil and mungbean were grown predominantly under rainfed conditions, hence irrigation water use is not reported for RL, RWMb and RWJ systems; ***Values for RW and RM are system irrigation WUE and for RL, RWMb and RWJ are system total (rain and irrigation) WUE

Diversifying the rice-wheat system by incorporating mungbean as a third crop (RWMb) increased the annual food rice-equivalent yield by 2.3 Mg ha^{-1} under CT, and by 2.7 Mg ha^{-1} under CASI. Furthermore, the combination of diversifying the rice-wheat system by incorporating a jute crop (RWJ) and converting from CT practices to CASI boosted annual food productivity from 8.6 Mg ha^{-1} in rice grain equivalent yield (or 304 GJ ha^{-1} food energy) to 14.2 Mg ha^{-1} (470 GJ ha^{-1}).

From a Food-Energy-Water perspective, CASI practices increased rice-equivalent food grain productivity by 3–6% (depending on the cropping system) compared with CT practices. Moreover, in rice-wheat and rice-maize systems, CASI saved more than 12% of irrigation water, which improved irrigation water use efficiency (WUE) by 24 or 25% compared to CT. In other cropping systems, total WUE (including rainfall) increased by 4% for rice-lentil (RL) and 6% for rice-wheat-jute (RWJ). Mainly by eliminating tillage and reducing labor and water use, CASI practices saved energy in all cropping systems and increased energy use efficiency by 13–15% for rice-wheat, rice-maize and rice-lentil systems. There were also significant reduction of greenhouse gas (GHG) emissions (CO_2 equivalent), by 9% for the input-intensive rice-wheat and 26% for the rice-wheat-jute system.

These results demonstrate that smallholder farmers in South Asia can improve the Food-Energy-Water nexus in the eastern Rice-Wheat Farming System by adopting CASI practices. Additional improvements in Food-Energy-Water securities are feasible through system diversification by incorporating mungbean or jute into the rice-wheat system (facilitated by faster crop establishment with CASI), or through switching to rice-maize or rice-lentil cropping systems. Timsina et al. (2011) also report high system productivity from irrigated rice-maize and rice-wheat-mungbean cropping systems in South and SE Asia. The improvement of Food-Energy-Water securities and reduction of GHGs of the rice-wheat system from this CASI research in the eastern Rice Wheat Farming System resemble the outcomes from CASI practices across other parts of South Asia (Hari Ram et al. 2011; Aryal et al. 2015; Ladha et al. 2015; Gathala et al. 2015, 2016; Kumar et al. 2018). Notably, the greatest improvement to the Food-Energy-Water nexus in these irrigated farming systems stemmed from increased WUE. Conversely, in rainfed farming systems in South Asia (and other regions), the primary sources of improved Food-Energy-Water nexus are increases in food grain productivity and energy use efficiency.

22.3 Farm Household and Gender Impacts

22.3.1 Benefits for Female- and Male-Managed Households

The livelihood benefits for farm families who adopt CASI, and effects related to gender, are central to socioeconomic impacts. In case studies of 46 men and women farmers in the eastern Rice-Wheat Farming System, Rola-Rubzen et al. (2016) found that the impacts of CASI were quite diverse, and included savings in labor use, reduction in production costs, increased crop yields, higher net farm income and better household food security.

A follow-up interview survey of 1780 households in the eastern Rice-Wheat Farming System (Rola-Rubzen et al. 2019) compared the performance of CASI and CT practices for male-managed and female-managed farm households. Combining the male- and female-managed groups, the overall results indicate higher average yields, and thus better household food security, from CASI practices for kharif rice (3.4 Mg ha^{-1}), wheat (2.4 Mg ha^{-1}) and rabi maize (7.1 Mg ha^{-1}) compared with CT practices – respectively 3%, 13% and 8% greater (Table 22.2). The adoption of CASI practices also increased yields for spring maize, mungbeans and kidney beans – but not for mustard in the one reported district. Considering the traditional rice-wheat system and the relatively recent rice-maize system, farmers reported approximately 7% greater system food grain productivity under CASI than CT for both systems. As is common, farmers reported lower yields in these early years after adoption of CASI than were measured in on-farm trials – approximately 34% less for the rice-wheat system and 14% less for the rice-maize system. In the case of female-managed farms, the adoption of CASI also led to higher average yield for wheat in one district, and for rice in another district. Interestingly, female-managed farmers achieved slightly greater improvements in food grain yield from CASI adoption than male-managed farms.

Family labor is a key smallholder resource. Understanding farming systems and technology adoption requires knowledge of labor management and its allocation to different crops, livestock and off-farm activities. Overall, the adoption of CASI

Table 22.2 Crop yield and labor use (hired and family) under CASI cf. CT by crop and district[#]

	Yield (kg ha^{-1})			Hired labor (hr ha^{-1})			Family labor (hr ha^{-1})		
Crops/districts	CASI	CT	sig	CASI	CT	sig	CASI	CT	sig
Kharif rice									
Sunsari	3550	4112		195	478	***	181	93	*
Dhanusha	4293	3548	*	219	405	***	150	160	
Female	*4074*	*4008*		*121*	*392*	***	*180*	*151*	
Coochbehar	2328	1846	***	74	181	***	115	153	**
Female	*2109*	*1804*	***	*104*	*191*		*125*	*139*	
Malda	2382	2581	***	203	299	***	162	150	
Rangpur	5263	5294		549	614	**	335	419	**
Spring rice									
Rajshahi	5039	4666	***	360	491	***	360	495	***
Wheat									
Sunsari	2632	2244	**	160	156		61	55	
Dhanusha	2072	1854		134	119		115	111	
Female	*2290*	*2152*		*115*	*131*		*86*	*103*	
Malda	1876	1759		121	140		116	240	***
Rajshahi	3136	2582	***	336	456	***	228	246	
Rabi maize									
Sunsari	6377	6514		146	326	***	59	83	
Coochbehar	4050	3575	***	85	100		72	248	***
Malda	3608	4060		97	170	***	154	161	
Rajshahi	11,022	9358	***	304	403	***	197	340	***
Rangpur	10,523	9350	***	529	527		337	369	
Kharif mung bean									
Rajshahi	1233	1137		371	361		258	206	*
Mustard									
Malda	723	834		159	119	*	47	39	
Kidney bean									
Sunsari	1905	1673		223	294		82	121	

Source: Rola-Rubzen et al. (2019)
Notes: Female-managed farm data reported in two districts for rice and one district for wheat; other data are for male-managed farms. ***significant at 1% level of alpha, **significant at 5%, *significant at 10%. [#]farm activities include land preparation, planting/transplanting, fertiliser application, insecticide/fungicide application, herbicide application, weeding and harvesting

saved 29% of total labor use (combining family and hired labor inputs) for the production of kharif rice, 16% for wheat and 27% for rabi maize (Table 22.2) – a major socioeconomic impact of CASI adoption. Often, saved family labor augments livelihoods through use in other farm or off-farm activities. Male-managed farms reported less hired labor use under CASI, notably for kharif rice in five districts, and for wheat and maize each in four out of five districts; and lower family labor use under CASI for maize in all districts, wheat in two districts and kharif rice in three districts. Female-managed farms also reported a lower level of hired labor use under CASI; but did not report any significant change in family labor input for these crops. Of course, family and hired labor are substitutes in many circumstances. The labor-saving effect of CASI is practically universal across regions and crops – even for vegetables, Schneider (2017) found labor savings from some conservation practices in Nepal.

In relation to production costs (Table 22.3), CASI incurred, in general, lower variable costs than CT for both male- and female-managed farms – overall, the savings for kharif rice, wheat and maize were 21%, 8% and 18% respectively. Male-managed farmers reported significant cost savings for kharif rice in five districts, wheat in three districts and maize in four districts. Similarly, female-managed farms using CASI saved costs for kharif rice production in both districts.

In this analysis, net crop income was calculated as harvest value less the variable costs of production, and thus is equivalent to gross margin. On male-managed farms, CASI practices generated greater average net crop income than CT for kharif rice by 50%, and maize by 60% (Table 22.3). Notably, average CASI wheat net income was nearly 2.5 times the CT net income. The adoption of CASI also increased net income compared with CT for spring rice, mungbeans and kidney beans, although not for mustard. On female-managed farms the adoption of CASI practices increased net income for kharif rice and wheat, approximately quadrupling and doubling net income respectively. Similarly, strong economic performance of CASI has been reported in the irrigated Rice-Wheat Farming System in north-west India (Jat et al. 2019; Shyamsundar et al. 2019) and elsewhere in South Asia (Erenstein 2010). Economic benefits from the adoption of CASI have also been observed in many rainfed farming systems in the Middle East, Africa and Latin America.

Considering the growing shortages of rural labor and the role of labor allocation in farm household system management, the estimation of returns to labor is important. Not surprisingly, the CASI boosts returns to labor by factors of 2.4 for kharif rice, 4.9 for wheat and 2.4 for maize compared with CT, largely because of labor savings and increased yield and income (Table 22.3). The increased returns to labor were substantial for both female- and male-managed farms for all crops and all districts except for mustard in one district. Given the substantial labor savings and high returns to labor, the overall effects of CASI adoption on rural labor markets in the Rice-Wheat Farming System is an important question for future investigation.

Overall, the survey results indicate substantial household benefits and strong socioeconomic impacts from CASI adoption, notably improved food security from increased yields and especially increased income, reduced labor requirements and

Table 22.3 Production cost, net income and returns to labor under CASI cf. CT by crop and district

Crops/districts	Product-ion cost (AU$ ha^{-1})			Net income (AU$ ha^{-1})			Return to labor (AU$ hr^{-1})		
	CASI	CT	sig	CASI	CT	sig	CASI	CT	sig
Kharif rice									
Sunsari	678	775		226	348		0.79	0.74	
Dhanusha	728	904	***	369	31	**	1.10	0.07	***
female	*613*	*957*	***	*472*	*14*	**	1.83	0.04	***
Coochbehar	232	327	***	463	234	***	2.55	0.72	***
female	*247*	*340*	***	*374*	*209*	***	1.71	0.65	***
Malda	380	392		344	369		1.09	0.88	*
Rangpur	668	819	***	1343	1189	**	1.56	1.25	***
Spring rice									
Rajshahi	681	920	***	1161	903	***	2.11	1.31	***
Wheat									
Sunsari	565	575		345	131	***	1.85	0.01	**
Dhanusha	626	593		104	30		0.55	0.17	
female	*542*	*618*		*238*	*100*		1.16	0.39	
Malda	399	449		179	112		1.07	0.32	
Rajshahi	846	1019	***	215	65	***	0.47	0.16	***
Rabi maize									
Sunsari	701	917	***	865	692		5.78	2.02	***
Coochbehar	363	462	***	621	348	***	4.24	1.12	***
Malda	497	437	***	402	470		1.85	1.52	
Rajshahi	916	1130	***	3639	1691	***	7.73	2.50	***
Rangpur	797	1052	***	2345	1710	***	2.85	2.16	***
Kharif mung bean									
Rajshahi	787	784		489	380		0.85	0.73	
Mustard									
Malda	249	244		234	344	**	1.18	2.32	***
Kidney bean									
Sunsari	690	832		1631	1183		5.28	2.92	*

Source: Rola-Rubzen et al. (2019)

Notes: Production costs are variable costs. Net crop income is equivalent to gross margin. Female-managed farm data cover two districts for rice and one district for wheat; other data are for male-managed farms. All estimates calculated directly from survey data. ***significant at 1% level of alpha, **significant at 5%, *significant at 10%

increased returns to labor for both female- and male-managed farms. Compared with other studies, the kharif rice yields reported in this research are similar to those described by Jat et al. (2019) in the early years after adoption of CASI, although they documented higher yields during the subsequent years. The net income from kharif rice is also comparable to the results of Jat et al. (2019) in the first two years after CASI adoption. However, Gupta and Sayre (2007) reported greater net crop income, perhaps because their study included land levelling practices.

Rola-Rubzen et al. (2016, 2019) emphasize the positive perceptions of CASI by farm women and men, as well as a variety of indirect benefits. Due to the additional income and saving of time, the benefits include better nutrition for the farm family, reduced drudgery for women, more time for other productive tasks or leisure activities and better education of children (Rola-Rubzen et al. 2016; Brown et al. 2017). In focus group discussions with 1182 female and male participants in the eastern Rice-Wheat Farming System, male farmers overwhelmingly agreed that the key benefits of CASI were less labor, less water, lower cost, and healthy soils (Rola-Rubzen et al. 2017). Farm women voiced similar perceptions, viz, the main benefits were less labor, less drudgery, less irrigation water, timely seeding and decreased costs. Both male and female farmers perceived CASI as a woman-friendly technology.

22.3.2 Farm-Household Resilience and Livelihood Risk Reduction

A large proportion of smallholder women and men are risk averse (Dixon 2003), meaning that many would trade-off less household income for reduced livelihood risk. For most South Asian smallholders, income from crops, whether in kind for home consumption or cash from sales of harvest produce, represents more than half of household livelihoods. Figure 22.2 shows Cumulative Density Functions for cropping system net income for CASI (averaged over partial and full) and CT practices (left quadrant) and for five rice-based cropping systems with CASI (right quadrant) estimated from the two years of on-farm trial data across the eastern Rice-Wheat Farming System, reflecting differences in farm and seasonal conditions. The cumulative density functions for CT and CASI practices represent the probabilities of obtaining particular minimum annual net cropping system incomes, in which higher probabilities (and less uncertainty) are associated with lower returns. CASI practices provided consistently higher net income than CT at all probability levels, suggesting that CASI technologies are likely to be superior to CT for good and poor soils, and for good and poor seasons. At 90% probability level, the annual net income from CT of AU$ 901 ha^{-1} compared with AU$ 1334 ha^{-1} for CASI. However, at the 50% probability level, annual net income with CT of AU$ 1590 compared to AU$ 2027 with CASI. Taken another way, a target net crop income (say, for escape from poverty) of at least AU$ 2000 ha^{-1} would be achieved with CASI in more than half of situations (51.6%) but only one-third (34.2%) of situations with CT.

The degree of superiority of CASI technologies over CT depends on the cropping system. For comparison purposes, the rice-wheat system is considered as the benchmark. The cumulative density functions for the cropping systems practiced with CASI showed the probabilities of obtaining minimum annual net crop income ranged widely, with the highest incomes from the rice-maize and rice-wheat-jute systems (Fig. 22.2). At 50% probability, annual net crop income exceeded AU$

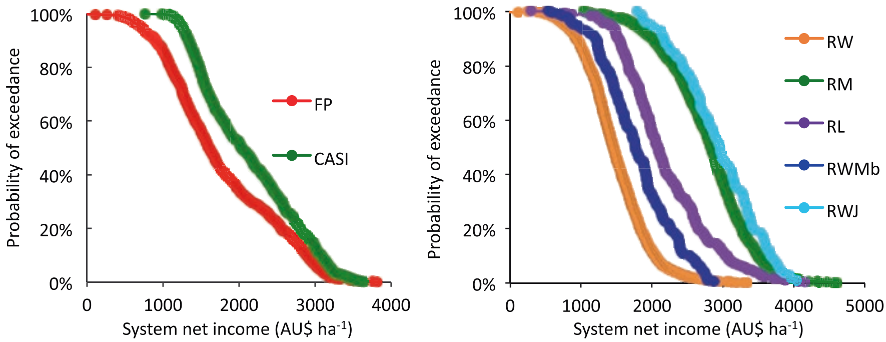

Fig. 22.2 Comparison of risks in obtaining system net income from CASI and CT (referred to as FP in figure). *RW* rice-wheat, *RM* rice-maize, *RL* rice-lentil, *RWMb* rice-wheat-mungbean and *RWJ* rice-wheat-jute. (Modified from Gathala et al. 2018b)

1455 ha^{-1} for the rice-wheat system, AU$ 2826 ha^{-1} for rice-maize and AU$ 2950 ha^{-1} for the rice-wheat-jute system, with intermediate net incomes for the rice-lentil and rice-wheat-mungbean systems. The chances of achieving a target net crop income of AU$ 2000 ha^{-1} was 11.7% from the rice-wheat system, while the probabilities would increase to 90% and 94.5% from the rice-maize and rice-wheat-jute systems, respectively. These results demonstrate the consistently high returns (relative to risk) of practicing CASI for rice-maize and rice-wheat-jute systems in the eastern Rice-Wheat Farming System.

Risk analysis for food productivity revealed that, at all probability levels, CASI practices had consistently higher yields than with CT. The annual food productivity from rice-maize system was about 50% greater than that from rice-wheat, and the rice-maize system was also more resilient to climate stresses (e.g., terminal heat stress or variable rainfall) than rice-wheat or rice-lentil (Islam et al. 2019). These findings suggest that CASI can decrease livelihood risks and increase farm household system resilience for resource-poor smallholder farmers in the Rice-Wheat Farming System. Because the research results span two years and a portion of the variability in the research results would arise from spatial variability in precipitation across the trial locations, the analysis suggests increased resilience to climate change variability. Further evidence of climate resilience could emerge from cropping systems simulations using historic (or projected) rainfall sequences for several decades.

There are limited studies on risk analysis of potential cropping systems comparing CT with CASI in South Asia using cumulative density functions. The consistently higher system productivity and higher net income with CASI compared to CT at all probability levels for the rice-maize system obtained in this study are consistent with findings of Gathala et al. (2015, 2016) for several locations of Bangladesh. Further research is required to estimate the reduced risks of practicing CASI compared to CT in long run.

22.4 Institutions for Scaling and Rural Transformation

22.4.1 Approaches to Scaling

The above results from on-farm trials and household surveys illustrate how adoption of CASI would improve livelihoods and system resilience for smallholders in the eastern Rice-Wheat Farming System, as in many other farming systems around the world. Many socioeconomic factors influence the adoption of CASI practices (Knowler and Bradshaw 2007; Pannell et al. 2014), often of equal importance to biophysical constraints. Institutions have played a key role in the adoption of CASI practices across the Rice-Wheat Farming System (Erenstein et al. 2008; Erenstein 2010; Keil et al. 2016) and in other regions of the world.

Accelerated adoption and scaling of CASI require an in-depth understanding of farming systems, public agricultural agencies, agribusiness, NGOs and the local community institutions which shape the incentives for farmer, business and public agency decisions (Tiwari et al. 2017; Gathala et al. 2018a – see also Fig. 22.1). The knowledge of adoption and scaling processes and the pathways to farming system and institutional change lie at the heart of agricultural and rural transformation. Naturally, many system linkages, feedback loops and uncertainties are embedded in farming systems and institutional change, i.e., it is far from a linear process.

These system approaches to scaling (Sinclair 2017) require broad partnerships and constructive engagement between research, development organizations, business and farmers in order to enable and foster broad system change and rural transformation. There are a variety of tools to assist the process of formulating, targeting and implementing effective scaling strategies (Woltering et al. 2019). In marked contrast to traditional perspectives concerning the dissemination of technologies, systems approaches to scaling call for iterative action research, continuous learning and adaptive management, and increased capacity of farmers, local institutions and value chains.

22.4.2 Value Chains

The provision of inputs and services for effective NT seeding is a critical challenge for CASI in many farming systems, especially in the case of NT drills (Keil et al. 2016). Accordingly, a series of ACIAR projects supported the development of the Happy Seeder NT drill and related machinery in India, Pakistan and Bangladesh – a major technological breakthrough which enabled the successful direct seeding of wheat seed under heavy rice straw. However, until recently, weak institutions and incentive structures slowed the manufacture and uptake of the Happy Seeder and other NT drills, with the consequence that rice straw burning, ploughing and conventional sowing of wheat persisted.

Because the burning of rice straw aggravated the already-critical levels of air pollution across north-west India, a policy study analyzed Happy Seeder value chains for NT (Loch et al. 2018). Despite the clear economic viability of the Happy Seeder (Shyamsundar et al. 2019), the value chain analysis revealed, *inter alia*, a lack of capacity in custom hire centers for effective operation and maintenance of Happy Seeder equipment, and for the business arrangements for effective service provision. Also, manufacturers of the Happy Seeder lacked confidence in farmer demand, especially before subsidies for farm equipment purchase were extended to include the Happy Seeder. Long supply chains for Happy Seeder machinery is another constraint in some areas, particularly in the eastern Rice-Wheat Farming System because the majority of manufacturers are located in north-west India.

The results of the Happy Seeder value chain analysis were valuable input to the policy dialogues leading up to the launching of the Government of India program for the provision of NT planting services. This program resulted in a massive expansion of the number of NT drills on farmers' fields during the 2018/19 wheat season in north-west India and a reduction in the number of districts that routinely burnt rice straw before planting wheat. The strengthening of the value chain for delivery of the Happy Seeder and other NT drills generated substantial additional income and socioeconomic benefits along the Happy Seeder value chain from manufacturers to service providers and farmers.

Of course, successful scaling of CASI depends on the strengthening of many other input and produce value chains. Rural entrepreneurship plays a key role in value chain development, but so too the social capital of farmers' groups and local communities.

22.4.3 Social Capital

Institutional innovations play multiple and diverse roles in farmer-to-farmer learning, irrigation water management, micro-finance, marketing and participatory evaluation of CASI. In West Bengal, farmers' clubs provide outstanding support for CASI, including input acquisition, provision of machinery services, and produce marketing. A notable institutional innovation of one club is the provision of contract services for maize crop establishment under CASI in neighboring villages (Gathala et al. 2018b).

One successful form of social capital for CASI R&D is the innovation platform, which links farmers researchers, extension agents, traders, NGOs, and other development actors to foster co-learning and adaptive innovation (Makini et al. 2013). Underpinned by social network analyses, the Sustainable and Resilient Farming Systems Intensification Project established about 30 innovation platforms in the eastern Rice-Wheat Farming System (Brown et al. 2017). A number of factors were associated with successful Sustainable and Resilient Farming Systems Intensification Project innovation platforms, including consideration of farmers' perceptions, effective NT machinery value chains, an enabling environment for entrepreneurship, and broad engagement of stakeholders including women (Cummins 2018). Table 22.4 compares the relative strength of the innovation platforms and the resulting impacts.

Table 22.4 Innovation platform capacities and impacts

Capacity and impacts	Bangladesh	Nepal	West Bengal	Bihar
Demonstrated changes in crop management	1.75	1.53	2.38	2.05
Financing (savings, loans, self-funding of CASI machinery)	2.44	0.87	2.00	2.07
Crop input retail business services	2.22	1.60	2.50	2.67
Adoption of CASI seeding systems	2.50	1.50	2.17	3.00
Access to CASI machinery	2.00	1.70	1.17	3.00
Knowledge (group awareness of improved farming systems)	1.17	1.90	1.33	2.20
Attitudes (positive attitudes and motivation amongst members to increase profitability and productivity	2.17	2.6	2.00	2.60
Skills (relating to crop production, farm business management)	2.00	2.00	2.00	2.60
Aspirations (farmers being ambitious, future plans for success)	2.00	2.20	1.34	3.00
Social Capital (how well the group and community work together, leadership prominence)	2.83	1.90	1.67	3.00

Source: Cummins (2018)
Notes: Scores range from 0 = nil/poor to 3 = significant/outstanding

22.4.4 Spillovers

Several studies have shown that spillovers between states, countries and regions account for a substantial portion of the returns to research in the USA and in developing countries. In South Asia, the Rice-Wheat Consortium generated high payoffs from the coordination of research and sharing of knowledge about resource conserving technologies, including CASI, across the Rice-Wheat Farming System of South Asia (Seth et al. 2003; TAAS 2017). At a regional Happy Seeder Policy project workshop in 2018, National Agricultural Research System leaders from four South Asian countries agreed in principle to the establishment of the South Asian Regional Platform (‘SARP4CASI’) for CASI knowledge sharing. There is scope for further research on the determinants of spillover effectiveness in different contexts and the influence on CASI scaling pathways and socioeconomic impacts.

22.5 Conclusions and Lessons

Considering the expanding demand for food this century, strengthening the underlying natural resource base and Food-Energy-Water securities is an essential foundation for the required sustainable intensification of agriculture. One effective sustainable agricultural development option is CASI, which has been adapted to many types of farming systems around the world, including the Rice-Wheat Farming

System that underpins South Asian food and nutrition security. As an illustration of the nature and magnitude of socioeconomic impacts from CASI, this chapter reviewed the evidence arising from the successful adaptation of CASI to six different farming subsystems of the eastern Rice-Wheat Farming System spanning Bangladesh, eastern India and Nepal. The results were compared with findings in other irrigated and rainfed farming systems.

The research results from the eastern Rice-Wheat Farming System show that CASI can substantially improve smallholder household food security and strengthen the Food-Energy-Water nexus. On-farm trial results showed increases of food energy production from 304 GJ ha^{-1} in the RW cropping system to 540 GJ ha^{-1} in intensified and diversified cropping systems. CASI also increased energy and water use efficiencies by 15% and 24% respectively, and reduced GHG emissions (CO_2 equivalent) from the improved CASI-based cropping systems. These results are similar to those observed in other Asian irrigated farming systems. However, in rainfed farming systems in Africa and the Middle East the increases in food productivity and energy efficiency are often larger than for water use efficiency.

Substantial household benefits and socioeconomic impacts flow from smallholder adoption of CASI in the eastern Rice-Wheat Farming System. Both female- and male-managed farms benefited from increased food crop yields and thus improved household food security. Two further key findings were the major savings in farm labor requirements for rice, wheat and maize production and major increases of net crop income. Consequently, the returns to labor more than doubled for rice and maize, and more than quadrupled for wheat. The research results also confirmed that CASI reduced production risk for smallholders. Both female and male farmers in the eastern Rice-Wheat Farming System perceived CASI as a ‘woman-friendly’ technology. They summarized the major benefits as less labor/drudgery, less irrigation water, timely sowing, decreased production costs and healthier soils. Overall, CASI strengthens system resilience in the irrigated Rice-Wheat Farming System of South Asia. In rainfed farming systems, CASI also increases farm income and reduces labor requirements, and especially reduces seasonal production risk.

The wider rural non-farm economy also benefits from the scaling of CASI adoption. In the eastern Rice-Wheat Farming System increased local employment and business income from expanded input and grain value chain activity were observed. Farmers’ clubs in West Bengal acquired and distributed farm inputs at competitive prices, provided NT machinery services to members and contract services to neighboring communities for CASI crop establishment. Social capital increased, especially through the innovation platforms that brought together farmers, local business, extension workers and researchers for co-learning and capacity development. Such CASI innovation platforms have also been very effective in rainfed farming systems in Africa. In the eastern Rice-Wheat Farming System, the convergence of research activities with national and State livelihoods development programs in West Bengal fosters the scaling of CASI. Active engagement of policy makers is an essential feature of CASI scaling approaches in the Rice-Wheat Farming System in South Asia, as in other regions.

The choice of the CASI approach enabled a win-win-win for intensification along with positive environmental and socioeconomic outcomes. The size of the target population and the severity of poverty, food insecurity, resource degradation and climate stress ensured potentially large socioeconomic impacts from scaling of CASI. Enabling factors for scaling include efficient service delivery and value chains, strengthened social capital and adjusted policy and institutional settings. These various factors interact and so a complex systems approach to further research and scaling would be most effective.

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