Developing resource efficient and climate smart production systems in the Eastern Gangetic Plains

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Contents

Executive summary

The Eastern Gangetic Plains (EGP) of Bangladesh, India and Nepal is home to 450 million people, with the world's highest concentration of rural poverty and a strong dependence on agriculture for food security and livelihoods. Projections indicate that climate change will adversely impact on agriculture in the region and jeopardise food security and rural livelihoods. The EGP has the potential to become a major contributor to South Asian regional food security, approaches are needed that can help farmers both adapt to climate change and mitigate emissions while at the same time maintaining or improving food security. Through the Sustainable Development Investment Portfolio (SDIP), the Australian Centre for International Agricultural Research (ACIAR) has been funding work to test and scale resource efficient and climate smart production systems in the EGP. This work includes documenting future climate change in the region and its potential impacts on agriculture; demonstrating farming techniques that are sustainable from a resource management perspective and have lower input related emissions; measuring the impact of these farming techniques on soil carbon; regional implications of different levels of adoption; and demonstrating the ability for profitable, climate smart business models for smallholders.

The farming systems improvements tested in in the program are based on Conservation Agriculture based Sustainable Intensification (CASI), which is a broader form of Conservation Agriculture (CA) that incorporates agronomic, socio economic and institutional aspects of food production, including more sustainable agroecosystem management, increased input use efficiency and increased biological and economic productivity. These are based on the CA principles of minimizing soil disturbance, ensuring soil cover and diversification through rotations. The research and development activities were conducted in 40 nodes in eight districts across the EGP in Bangladesh, India and Nepal. These locations were chosen specifically to test techniques in a range of agro-ecological settings, as well as to enable cross-border comparison of results, and to explore the effects of institutional and policy settings.

Results from more than 400 participatory multi-year field trials demonstrated that CASI practices improved productivity (3 – 6%) and profitability (17 – 41%) while reducing input related emissions (6 – 12%), water (11%), energy inputs (6 – 11%) and labour requirements in rice-wheat, rice-maize and rice-lentil systems in the EGP. For individual crops, CASI treatments reduce emissions on average by 14% for wheat, 10% for maize, 18% for lentil and 8% for rice. For cropping systems, emissions were reduced between 9 – 12% through the use of CASI technologies. Rice-rice systems are the most emissions intensive cropping pattern, thus replacing rice-rice systems with any of the other alternatives can reduce emissions by 37% - 65% for two crops, and even when a third crop is added (i.e. mungbean or jute), emissions are still 27 – 39% lower.

To date, up to 91,000 households are using CASI technologies in the project areas, with almost 220,000 people exposed to these new techniques through field days, training and other project and partner activities. The most widely adopted technologies include zero-tilled wheat, maize and mustard, pulses, unpuddled transplanted rice in the boro season using a mechanised transplanter, and direct seeded rice. In total, the adoption of these technologies has covered 60,436 hectares, generated an additional $24 million for smallholder farmers, saved 12,000 ML of water from being pumped, and reduced emissions associated with crop inputs by 11,000 tonnes CO_2-e.

Farmers using CASI constitute between 0.3% up to 6% of farming households in target locations, with these numbers being achieved within the five year project lifespan. The potential for scaling to 10% of the area of these systems would increase productivity by 958,000 tonnes, generate $1,041 million (AUD) in farm profits, reduce irrigation water use by 1,096 GL, reduce energy use by 6 PJ and reduce carbon emissions by 371,000 tonnes of CO_2-e. Increasing use to 50% of the area of these systems would increase productivity by almost 5 million tonnes, generate more than $5 billion (AUD) in farm profits, reduce irrigation water use by 5,480 GL, reduce energy use by over 30 PJ and reduce carbon emissions by almost two million tonnes of CO_2-e.

Impacts on soil carbon have been monitored within the life of the project, with CASI systems appearing to have a positive impact on both the amount and types of carbon present in the upper soil layers. However, changes in soil organic carbon (SOC) are often variable in the early stages of using CA techniques, and stronger trends are often only seen in the longer term. This is supported by our modelling results which show potential for 150% increase in SOC over a 35 year time frame.

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

There are several elements associated with climate change adaptation and mitigation that have not been measured, and which should be pursued in the future. This includes:

- Tracking changes in fertilizer use associated with CASI approaches to see if fertilizer use is reduced, with a focus on nitrogen fertilizer.
- Tracking the performance of CASI approaches under extreme weather events.
- Measurement and/or simulation of direct emissions from individual fields and comparisons to the input-related approach used here.
- Longer term monitoring of soil carbon trends under CA based systems and during transitions to different farming systems with alternate crop rotations.

1 Background

Changes to the global climate in the mid and longer term are projected to manifest in higher temperatures, more variable precipitation rates, and more extreme weather events such as floods, droughts and heat waves. These factors will have significant impacts on agricultural production systems, in terms of the kinds of crops we can grow, the resources required for their production, and the total nutrition we obtain. In addition to facing the impacts of climate change, agriculture is also a key contributor to greenhouse gas emissions, and pressure is mounting to reduce the current levels of emissions. For agriculture, climate change is a dual burden, in terms of the need to find ways to both enhance farmers' resilience to changes in climate, and to reduce emissions from agriculture.

The Eastern Gangetic Plains (EGP) of Bangladesh, India and Nepal is home to 300 million people, with the world's highest concentration of rural poverty and a strong dependence on agriculture for food security and livelihoods. Projections indicate that climate change will adversely impact on agriculture in the region and jeopardise food security and rural livelihoods. The EGP has the potential to become a major contributor to South Asian regional food security, but rice and wheat productivity remain low and diversification is limited because of poorly developed markets, sparse agricultural knowledge and service networks, and inadequate development of available water resources and sustainable production practices. Labor shortages exist and are becoming more acute. These factors lead to smallholder vulnerability to climate and market risks that limit farmer and private sector investments in productivity-enhancing technologies. The level of poverty and high level of reliance on agriculture means approaches are needed that can help farmers both adapt to climate change and mitigate emissions while at the same time maintaining or improving food security.

The Sustainable Development Investment Portfolio (SDIP) is an Australian Government initiative, coordinated by the Department of Foreign Affairs and Trade (DFAT). It aims to improve the integrated management of food, energy and water in South Asia, to facilitate economic growth and improve the livelihoods of the poor and vulnerable, particularly women and girls, in the context of climate change. ACIAR's contribution to the portfolio is in maximising agriculture's contributions to sustainable food systems, including testing and scaling sustainable and resilient farming systems. As part of the ACIAR SDIP program, sustainable farming approaches for smallholders have been tested that demonstrate improved resource-use efficiency and counter the impacts of climate change, decrease input related emissions, and increase carbon storage in soils.

This report brings together the findings of the program by synthesizing the likely future trends in climate and their implications for agricultural production. We then summarize the results of extensive on-farm trials that tested sustainable farming systems and discuss how they relate to climate change adaptation. Finally, we model the mitigation potential of conservation agriculture based approaches if adopted at local and regional levels. The practice changes examined also have positive impacts on soil health in terms of the amount and types of carbon present, and improved soil structure. At the same time, these climate smart farming systems can be profitable for farmers and local businesses, creating new employment opportunities for women and rural youth. We include research findings published from related projects in the region and policy drivers to situate this work in the wider regional context. The work of the program has contributed to a better understanding of climate change impacts through synthesis of the likely trends and their implications for agricultural production at the regional level.

1.1 Climate change trends and impacts on agriculture in South Asia

Over the past 50 years, changes to the climate of the EGP have already been documented. Annual mean temperatures have increased by around 1°C, and the number of extreme heat days has increased while extreme cold days have decreased. There has been a slight decrease in annual precipitation and rainfall intensity has risen. These have influenced optimal planting times and the cropping season length, which have shifted through time (Aryal et al., 2019); IPCC, 2007). Over the next century, climate change will adversely impact the agriculture sector in South Asia, jeopardising food security and rural livelihoods. The information summarised in this section is reported in full in Dawson (2019), in a report commissioned to synthesise likely climate projections and their influence on agriculture in the EGP.

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

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

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

2 Testing sustainable farming systems

The impacts of climate change include increased temperatures, more variable precipitation patterns and more extreme events including extreme heat and cold. These conditions mean farmers need to be able to adapt their farming systems to conditions where planting dates and growing seasons change, water availability is decreased, extreme events like drought and flood become more frequent, and new pests and disease patterns emerge.

Farming systems trials were tested based on conservation agriculture (CA) principles, which includes a mix of minimizing soil disturbance, maintaining continuous soil cover, and crop diversification and rotation. The portfolio of technologies tested includes improved varieties of rice and wheat, crop diversification (maize, lentils, oilseeds, leafy vegetables), crop management strategies (zero and strip till (ZT, ST), relay and intercropping, stubble/residue retention, improved water management) and small-scale mechanization (e.g. different planting techniques). The combination of these practices applied within effective institutional settings is referred to as conservation agriculture based sustainable intensification (CASI), and are demonstrated to improve the climate resilience of farming systems in the EGP. The terms CASI and CA are used interchangeably throughout this report.

CASI techniques incorporate crop management techniques that allow adaptation to weather variability and climate change through a range of methods:

- Reduced or no tillage crop establishment using mechanisation (i.e. zero till) saves labour, improves timeliness of operations, and preserves soil structure to build soil carbon levels.
- Adjusting crop choice and planting dates to cope with changes in rainfall timing and quantity
- Incorporating varieties with different growth periods helps spread risk associated with extreme weather events
- Maintaining residues for soil cover increases soil carbon and reduces erosion in extreme weather events
- Including annual legumes in the crop rotation can contribute to reduced use of synthetic nitrogen fertilisers
- Testing effective management options for associated emergent pest (herbicides) and disease problems. A combination of these approaches leads to reduced water use by maintaining soil water content through reduced evaporation, crops with lower water use requirements and better irrigation management methods.

More than 400 participatory field trials were conducted between 2015 - 2017 in 40 nodes (each node consisting of one or more villages) in eight districts across three countries. These field results, in conjunction with simulation using the APSIM model, have been used to examine trade-offs, resilience and stability of technology performance in different locations and under future climate scenarios. Detailed descriptions of site characteristics, methodology and results can be found in (Gathala, n.d.-a, n.d.-b, n.d.-c; Islam S. et al., 2019). Table 1 contains a summary of the treatments used, ranging from conventional tillage (CT, T1) to partial (T2, T3) and full CASI systems (T4). Results from field trials were considered both on an individual crop basis and from a systems perspective (i.e. Rice-Maize (RM), Rice-Wheat (RW), Rice-Lentil (RL) and Rice-Rice (RR)). Results are presented to show the performance of CA techniques compared to Conventional Tillage (CT), and to show the impacts of diversification for example from rice-rice systems. The data have been summarised as an average across all sites with the particular cropping system. They are reported in a series of publications, including Islam et al. (2019) and Gathala et al. (n.d.-a; n.d.-b; n.d.-c). Although the rice-rice system sample size is small and limited to one geography, it does provide strong indicative results that show higher impacts in diversifying from these systems. This requires further research to confirm initial results. Improved outcomes were observed including improved profitability and productivity, household nutrition and food security; and reductions in labour, water and energy inputs associated with crop production systems.

Table 1 Summary of treatments tested in on-farm research, modified from Islam et al. (2019; pp 5).

Treatment	Rice	Wheat, Maize, Lentil
T1 (Conventional Tillage, CT)	After harvesting previous crop, 1-2 tillages at optimum soil moisture performed on first pre-monsoon showers. After start of full monsoon 2 -3 passes of wet tillage, including 1 pass to level the field. 30 – 35 day old seedlings manually transplanted using 3 - 4 seedlings per hill on a random basis, with a row spacing of approximately 20 cm.	**Wheat:** In the residual moisture of the previous rice crop, 1 pass of the tyne cultivator/rotary tiller followed by manual broadcasting of wheat seed and fertilizer together, and then 2 - 3 passes of the cultivator or rotary tiller to incorporate. **Maize**: In the residual moisture of the previous rice crop, 2 passes of the tyne cultivator followed by broadcasting of fertilizer, then 2 - 3 passes of the rotary tiller/cultivator, then a planking before maize seed sown. Maize seed planted manually at a depth of 4 – 5cm; 60 cm row and 20 cm plant spacings were maintained. **Lentil:** Immediately after the harvest of rice, lentil seed and fertilizer broadcast together, followed by 1 pass of the tine cultivator/rotary tiller in the residual soil moisture. Alternatively, relay planting into the standing rice crop was practiced, where lentil seed was broadcast before harvest.
T2 (Partial CASI)	Same as T1	Glyphosate sprayed 4 - 7 days before sowing the next crop to eliminate existing annual and perennial weeds. Rice stubble was retained to a height of 15 - 20 cm (1.5 to 2.5 t ha^{-1}). The wheat/maize/lentil crop was direct seeded in a single pass without any prior tillage and using the multi-crop zero-till planter. In wheat and lentil 20cm row spacing was maintained, for maize 60cm row and 20cm plant spacing.
T3 (Partial CASI)	Glyphosate sprayed 5 - 10 days before seeding. Rice direct seeded using multi-crop planter in a single pass, with 25-30 kg ha^{-1} of rice seed applied at 2 - 3cm depth, row spacing at 20 cm. Pre-emergence herbicide applied within 3 days of sowing. In exceptional situations unpuddled mechanical transplanting was performed if field conditions did not permit direct seeding of rice due to heavy rains and/or flooding.	Same as T2
T4 (Full CASI)	Glyphosate sprayed 5 - 10 days before transplanting. Mechanical rice transplanter used in an unpuddled, untilled field with 2 - 3cm standing water, using 17 - 25 day old seedlings with 22 - 24cm row and 12cm hill spacing. In the rare instances when a rice transplanter was unavailable the crop was manually transplanted, maintaining consistency of seedling age and number, and row and hill spacings.	Same as T2

2.1 Improved resilience to climate change and climate variability

2.1.1 Farming systems trials

Improved outcomes were observed when using CA techniques compared to CT, including improved productivity (3 – 6%) and profitability (17 – 41%), and a reduction in irrigation water use (11%), energy inputs (6 - 11%) and carbon emissions (6 – 12%) associated with crop production systems (Table 2, Table 4). When considering CA coupled with diversification from Rice – Rice systems, the impacts were even more pronounced (Table 3). While maintaining productivity of total systems, profitability was increased by 47 – 168%, with Rice-Wheat-Jute systems the most profitable. Energy and emissions were also significantly reduced, by up to 60% and 65% respectively for Rice-Lentil systems.

Table 2 Summary – % change for CA techniques compared to conventional tillage, based on data in Tables 3 - 9 (Table 4 - Table 10). RR Rice-Rice; RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.

Indicator	Cropping System					
	RR	RW	RM	RL	RWMb	RWJ
Productivity (t/ha)		3%	4%	6%	6%	3%
Profitability (AUD $/ha)		26%	17%	19%	41%	17%
Irrigation Water Use (ML/ha)		-12%	-11%			
Energy inputs (MJ/ha)	-10%	-10%	-7%	-9%	-11%	-6%
Carbon equivalent emissions (tCO2-e/ha)	-11%	-12%	-9%	-10%	-10%	-6%

Table 3 Summary – % change for CA techniques compared to conventional Rice-Rice systems, based on data in Tables 3 – 9 (Table 4 - Table 10). RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.

Indicator	**Cropping System**				
	RW	RM	RL	RWMb	RWJ
Profitability (AUD $/ha)	47%	163%	115%	77%	168%
Energy inputs (MJ/ha)	-40%	-27%	-60%	-19%	-27%
Carbon equivalent emissions (tCO2-e/ha)	-48%	-37%	-65%	-27%	-39%

Table 4 Effects of CASI techniques on total productivity (t.ha^{-1}) for individual crops in the EGP (Islam S. et al., 2019).

Treatment	Yield (t.ha-1) - all					
	Rice	Wheat	Maize	Lentil	Mungbean	Jute
T1 (Conventional)	4.57	3.12	8.39	1.36	0.56	1.97
T2 (Partial CASI)	4.60	3.28	8.77	1.45	0.60	2.01
T3 (Partial CASI)	4.64	3.27	8.77	1.48	0.64	1.98
T4 (Full CASI)	4.70	3.28	8.85	1.45	0.59	2.04
Mean change in yield (T2 – T4) compared to conventional tillage (T1)	2%	5%	5%	7%	9%	2%

For individual crops, net income was increased by 17 – 34% using CA techniques, with net income for wheat increased by the highest amount (Table 5). System level net income is increased by a greater amount, almost doubling for rice-rice systems. Compared to conventionally tilled rice-rice systems, diversifying to alternative crops and using CA techniques can increase profitability by 47 – 168%.

Table 5 Effects of CASI techniques on profitability (Net Income: AUD$.ha^{-1}) for cropping systems in the EGP (Gathala, n.d.-a). *RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RR Rice-Rice; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.*

Treatment	Net income (AUD$/ha)											
	Rice	Wheat	RW system	Rice	Maize	RM system	Rice	Lentil	RL system	RR system	RWMb system	RWJ system
T1 (Conventional)	669	591	1,260	732	1,691	2,423	684	1,265	1,948	1,084	1,360	2,492
T2 (Partial CASI)	681	799	1,480	740	1,989	2,708	764	1,509	2,278	1,972	1,781	2,908
T3 (Partial CASI)	875	786	1,656	945	1,951	2,896	881	1,505	2,386	2,271	2,044	2,762
T4 (Full CASI)	832	799	1,632	924	2,011	2,937	843	1,459	2,313	2,126	1,921	3,042
Mean change in net income compared to conventional tillage (T1)	19%	34%	26%	19%	17%	17%	21%	18%	19%	96%	41%	17%
Mean change in net income compared to conventional RR systems			47%			163%			115%		77%	168%

Total water use was reduced by 5 – 13% when CA techniques (Table 6). Higher water savings were recorded in wheat, maize and lentil. Mungbean is a short duration, low water use crop in any case and so the opportunities for water savings are lower. Rice crops shown here are rain-fed crops, and there is little opportunity to control water application and hence total water use remains the same. Irrigation water use was reduced by 11% at the system level (Table 7) when CA techniques were used.

Table 6 Effects of CASI techniques on total water use (ML.ha^{-1}) for crops and cropping systems in the EGP (Islam S. et al., 2019). *RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil.*

Treatment	**Total water use (ML.ha-1)**										
	Rice	Wheat	RW system	Rice	Maize	RM system	Rice	Lentil	RL system	Mungbean	Jute
T1 (Conventional)	9.79	1.84	11.63	10.35	2.67	13.01	12.89	0.43	13.22	0.58	7.12
T2 (Partial CASI)	9.82	1.60	11.43	10.25	2.40	12.67	12.59	0.39	12.81	0.56	7.12
T3 (Partial CASI)	9.83	1.61	11.45	10.28	2.46	12.74	13.06	0.39	13.27	0.56	9.11
T4 (Full CASI)	9.85	1.59	11.44	10.29	2.42	12.70	12.94	0.40	13.24	0.54	7.24
Mean reduction in water use compared to conventional tillage (T1)	0%	-13%	-2%	-1%	-9%	-2%	0%	-9%	-1%	-5%	10%

Table 7 Effects of CASI techniques on irrigation water use (ML.ha^{-1}) for crops and cropping systems in the EGP (Islam S. et al., 2019). *RW Rice-Wheat; RM Rice-Maize.*

Treatment	Water use - irrigation (ML.ha^{-1})			
	Wheat	RW system	Maize	RM system
T1 (Conventional)	1.49	2.08	1.78	2.31
T2 (Partial CASI)	1.25	1.83	1.52	2.11
T3 (Partial CASI)	1.26	1.79	1.54	2.01
T4 (Full CASI)	1.24	1.86	1.52	2.04
Mean reduction in water use compared to conventional tillage (T1)	-16%	-12%	-14%	-11%

Total energy inputs at the farming system level were reduced by 6 – 11% when CA techniques were used (Table 8). With CA techniques and diversification from Rice-Rice systems, the savings were much greater, between 19 – 60%. Rice-Lentil systems had the lowest energy inputs, likely due to lentils not requiring nitrogen fertiliser.

Table 8 Effects of CASI techniques on total energy use (MJ.ha-1) for cropping systems in the EGP (Gathala, n.d.-c). RR Rice-Rice; RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.

Treatment	Energy inputs (MJ.ha^{-1})					
	RR	RW	RM	RL	RWMb	RWJ
T1 (Conventional)	45,156	30,045	35,289	19,989	40,744	34,714
T2 (Partial CASI)	42,273	28,123	34,818	18,801	37,391	33,053
T3 (Partial CASI)	39,622	26,073	32,068	17,825	35,883	33,878
T4 (Full CASI)	40,404	26,923	31,832	18,157	35,964	31,401
Mean reduction in energy inputs compared to conventional tillage (T1)	-10%	-10%	-7%	-9%	-11%	-6%
Mean reduction in energy inputs compared to conventional RR systems		-40%	-27%	-60%	-19%	-27%

Figure 1 shows the relationship between yield, income and CO_2-e emissions, clearly demonstrating that with lower emissions, higher yields and profit can also be achieved. Similar work on intercropping of maize with leafy vegetables such as potato, peas, spinach and red amaranth showed that these systems were always more profitable than sole maize, although did require higher energy inputs, although this is offset by higher yields (Gathala et al., n.d.-b).

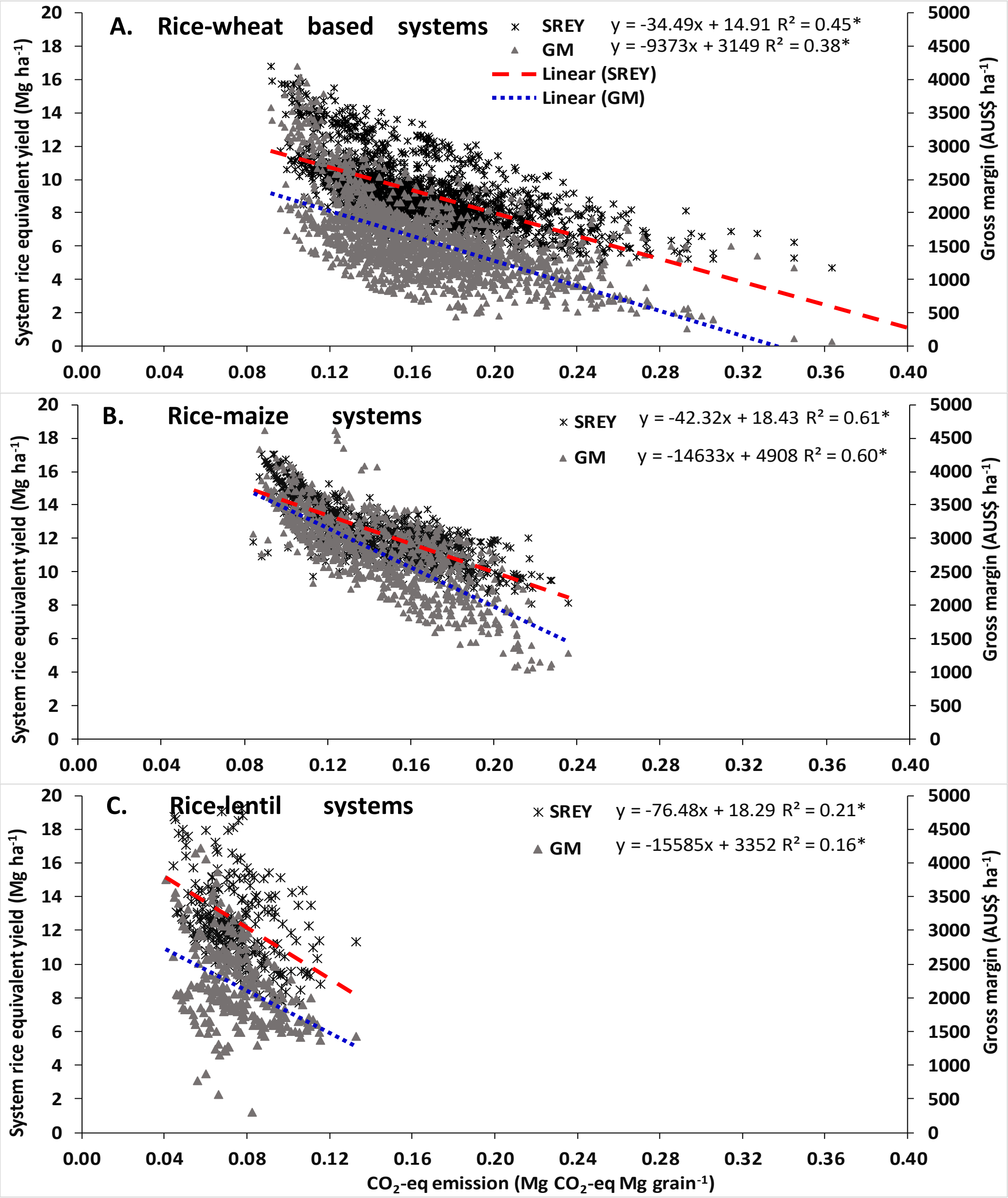

Figure 1 System rice equivalent yield (SREY) and gross margin (GM) against system CO_2-equivalent emissions for different cropping systems in the EGP (data include all treatments and districts): (A) rice-wheat systems; (B) rice-maize systems; (C) rice-lentil system. Values in parentheses show the total number (n) of data points. Taken from Gathala et al. (n.d.-b; Figure 5).

2.1.2 Effect of planting date on yield

Climate change will affect temperature and rainfall patterns in the EGP. This includes delayed onset of the monsoon, which can prolong harvest dates and hence the planting of dry season crops. The effect of planting date on wheat and lentil yield was examined using data from long-term trials. Yield reductions were recorded for wheat and lentil, including 22 kg/day for planting wheat after the start of December, and for lentil 62 kg/day after the 15th November. This kind of information is important under proposed climate change scenarios to maintain optimal planting dates, and to help farmers make decisions about which crop to plant in the dry season to maximise yield and profit.

2.2 Farm level mitigation – reducing GHG emissions

CASI approaches contribute to climate mitigation by reducing fuel inputs (i.e. for mechanised soil tillage and pumping for irrigation), minimising tillage and improving soil carbon levels, while maintaining or increasing productivity.

Carbon emissions (tCO_2-e/ha) were estimated for each crop and cropping system tested in the on-farm trials described above. This was done by accounting for the energy associated with crop inputs, and then converting energy inputs to tonnes of CO_2 equivalent (tCO_2-e/ha) using published conversion factors (Gathala et al., Forthcoming). Inputs included in the analysis were fertilizers, seeds, pesticides, fuel (for irrigation pumping and machinery operation) and human labour. The method accounts for the energy (and hence emissions) embodied in fertiliser. For a more detailed description of the methodology, see Gathala et al. (Forthcoming). The on-farm emissions data reported here does not include several potentially significant sources of emissions or mitigation options, such as soil carbon, nitrous oxide emissions from fertiliser application in the field, and direct methane emissions from flooded rice fields (see section 3.2.2).

2.2.1 Input related emissions associated with CASI systems

Table 9 shows input related CO_2-e emissions for individual crops and cropping systems. In all cases CASI results in a reduction of input related emissions of between 6 – 18%. Maize has the highest emissions on an area basis, followed by wheat, rice and lentil. For individual crops, CASI treatments reduce emissions on average by 14% for wheat, 10% for maize, 18% for lentil and 8% for rice.

Table 9 CO_2-equivalent emissions for main crops and cropping systems. Treatments for crops and cropping systems included T1 (Conventional system) comprised of puddled, transplanted rice followed by conventionally tilled maize, wheat or lentil. T2 (Partial CASI) comprised of puddled, transplanted rice followed by zero till wheat, maize or lentil. T3 (Partial CASI) comprised of zero till, direct seeded rice followed by zero till maize, wheat or lentil. T4 (Full CASI) comprised of unpuddled, transplanted rice followed by zero till maize, wheat or lentil. Reductions refer to the average of the three CASI treatments compared to the conventional system (Gathala, n.d.-c). *RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil.*

Treatment	***CO_2-equivalent emissions ($Mg.ha^{-1}$)***								
	Rice	Wheat	RW system	Rice	Maize	RM system	Rice	Lentil	RL system
T1 (Conventional)	0.70	0.84	1.55	0.68	1.14	1.81	0.70	0.30	1.00
T2 (Partial CASI)	0.70	0.72	1.42	0.68	1.02	1.70	0.69	0.24	0.92
T3 (Partial CASI)	0.58	0.72	1.30	0.59	1.05	1.63	0.65	0.24	0.89
T4 (Full CASI)	0.62	0.73	1.36	0.59	1.02	1.62	0.64	0.26	0.90
Mean reduction in emissions compared to conventional tillage (T1)	-10%	-14%	-12%	-9%	-10%	-9%	-6%	-18%	-10%

For cropping systems, emissions were reduced between 9 – 12% through the use of CASI technologies (Table 9). Rice-Rice systems are the most emissions intensive cropping pattern (even excluding direct methane emissions from flooded paddy), followed by Rice-Wheat-Mungbean, Rice-Maize, Rice-Wheat-Jute, Rice-Wheat and Rice-Lentil. Replacing Rice-Rice systems with any of the other alternatives can reduce emissions by 37% - 65% for two crops, and even when a third crop is added (i.e. Mungbean or Jute), emissions are still 27 – 39% lower. More details on energy and emissions reductions for individual crops and for sites across the EGP can be found in (Gathala, n.d.-c).

Table 10 CO_2 emissions from cropping systems using different production methods (Gathala, n.d.-c). *RR Rice-Rice; RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.*

Treatment	***CO_2-equivalent emissions ($Mg.ha^{-1}$) – Systems***					
	RR	RW	RM	RL	RWMb	RWJ
T1 (Conventional)	2.61	1.55	1.81	1.00	2.11	1.71
T2 (Partial CASI)	2.42	1.42	1.70	0.92	1.93	1.61
T3 (Partial CASI)	2.26	1.30	1.63	0.89	1.88	1.67
T4 (Full CASI)	2.31	1.36	1.62	0.90	1.87	1.52
Mean reduction in emissions compared to conventional tillage (T1)	11%	12%	9%	10%	10%	6%
Mean reduction in emissions compared to conventional RR systems	-	48%	37%	65%	27%	39%

2.2.2 Emissions not accounted for – CO_2, methane and nitrous oxide

Input related emissions quantified above are one part of the emissions budget, but other potentially significant sources of emissions include direct CO_2 emissions from soil, nitrous oxide emissions (N_2O) from fertiliser application, and direct methane (CH_4) emissions from flooded rice fields. These emissions are important as their global warming potential (CO_2-e) compared to CO_2 is much higher, at 25 times for CH_4 and 298 times for N_2O. These have not been measured directly within the SRFSI project, but there are reported figures from similar areas in the Indo Gangetic Plains (IGP) including those based on direct measurement and simulation. Direct soil emissions are highly influenced by tillage, residue and water management, and the timing and method of nitrogen application, and so the level and behaviour of these emissions is very context specific and varies widely (Sapkota et al., 2015).

CH_4 emissions occur under anaerobic conditions in flooded rice paddies, and in India account for 21% of total agricultural emissions (Sapkota et al., 2015). Reducing the number of irrigation events and the duration of flooding for rice, as is practiced under CA systems, can reduce CH_4 emissions, although this may in turn increase N_2O emissions. This was the case in a two year study in Haryana, India; where CA practices were used and water was not left standing in the field for longer than a day, no CH_4 emissions from rice were detected, while CT systems averaged 24.32 $kgC.ha^{-1}$ from methane emissions (Sapkota et al., 2015). However, the CA system had higher cumulative emissions of N_2O than then CT system. Other studies on temperate soils have shown that even with increased N_2O, lower CH_4 and CO_2 emissions compensate to reduce the net global warming potential of CA by up to 20% (Mangalassery et al., 2014).

The IPCC recommendation (2006) is that 1% of N applied is lost as N_2O emissions. However, a study in the northwest IGP showed losses of applied N in rice as 1.9% for CT and 2.5% for CA; while for wheat losses were 1.7% for CT and 1.9% for CA, both much higher than the 1% emission factor recommended by the IPCC (Sapkota et al., 2015). Time also influences emissions, and there is evidence to suggest that N_2O emissions are only elevated in CA systems within the first ten years of shifting from conventional systems (Oertel, Matschullat, Zurba, Zimmermann, & Erasmi, 2016).

In a comprehensive study in the IGP, gross Global Warming Potential (GWP) based on measured emissions (CH_4 and N_2O) combined with input related emissions showed no difference in emissions when considered on an area basis, but significant differences when scaled against grain energy yield (GJ/ha). Global warming potential intensity ($kgCO_2$-eMJ-1) was significantly lower for full CA systems (0.08 kg CO_2-e.MJ^{-1}) compared to partial CA (0.11 kg CO_2-e. MJ^{-1}) and CT systems (0.14 kg CO_2-e. MJ-1) (Ladha et al., 2016).

In Haryana, a study on emissions from CT and CA systems was undertaken using direct measurement of CH_4 and N_2O coupled with input related emissions. CA systems reduced CH_4 emissions by 56% with no significant increases in N_2O emissions. Diversifying rice with maize in the dry season reduced GWP by 38% (Tirol-Padre et al., 2016).

Input related emissions combined with seasonal CH_4 and N_2O fluxes estimated using emissions patterns based on field measurements in Haryana found that GWP of wheat was 8% lower under CA than CT. Importantly, emissions of N_2O and CH_4 from the soil contributed only 14% of total emissions for wheat and 15 - 18% for rice (Kumar et al., 2018). Rice itself had much higher GWP, three times that of wheat. At the system level, total GWP was 15 – 30% lower with CA compared to CT.

These studies demonstrate the variability in emissions of N_2O and CH_4, as influenced by management practices, soil type and climate. More work is needed in the study sites of SRFSI to quantify direct emissions, although in similar systems they have contributed less than 20% of total emissions.

2.3 Observed impacts on soil health

Soil organic matter is crucial for soil fertility, water retention and maintenance of crop productivity (Awale et al., 2017), and is heavily influenced by management practices such as tillage, residue retention and fertiliser regimes. Soil organic matter includes carbon (C) and nitrogen (N) and is present in different amounts and types depending on soil type, climate and production systems. Soil organic matter includes the different micro sources of C and N which represent a multitude of interrelated soil processes and functions (Awale et al., 2013), and which decompose at different rates. Accumulation of carbon, particularly available carbon, in the surface soil layers improves infiltration and water holding capacity, reduces erosion, improves nutrient recycling and soil biodiversity, and increases fertilizer efficiency (Haddaway et al., 2017). During intense precipitation events, soils are prone to erosion which contributes to carbon emissions (Lal, 2003). Soils which are cultivated under reduced tillage often have higher soil organic matter and have been shown to have lower soil losses (Kurothe et al., 2014). Direct studies within SRFSI have included soil analysis of long-term trials to quantify changes to soil carbon levels, and a detailed study on the carbon source pools, or types of carbon that are present in CA and CT systems.

2.3.1 Direct measurements of soil carbon

Across the study sites, the soil organic C concentration varied due to climate, edaphic factors, as well as being influenced by management practices (Mandal *et al*. 2007). In general, soil organic C concentrations increased from west to east and from south to north, following the total annual rainfall (Sinha et al., 2019).

As reported by Sinha et al. (2019), soil analysis after three years of on-farm trials in the SRFSI field sites showed that soil organic carbon (SOC) concentrations in the upper soil layer (0-15 cm) were significantly higher under the CA than CT practice in three locations in India (Madhubani, Coochbehar and Malda nodes), but similar in other project locations (Sinha et al., 2019) (Table 11). In Sunsari (Nepal), even at the research station site monitored over a 3-year period, SOC at the research station monitored over the same period showed inconsistent trends under CA relative to CT practice, reflecting the high variability of total SOC concentrations in these districts. It is possible that the most easily broken down part of SOC (the labile fraction, such as hot water soluble C), may be a more sensitive indicator to changes in tillage practices. For example, hot water soluble C was 29% higher under the CA sites than CT practice in Coochbehar (282 versus 219 mg C kg-1) and 36% higher in the Malda nodes (281 versus 245 mg C kg-1) (Sinha et al., 2019). Cropping system did not influence SOC concentrations, with the main farming systems of rice-wheat and rice-maize similar in all districts in the upper soil layer (0-15 cm) (Sinha et al., 2019). Total N concentration followed a similar trend.

Table 11 Changes in soil organic C (mean ± s.e.m.) under CA after 3 years in 7 districts of the EGP. In parenthesis are listed the number of paired samples for each tillage practice; ns, not significant (Sinha et al., 2019; pp 10).

District	Soil organic C (%)		
	Conventional Tillage	Conservation Agriculture	Sig. level
Rangpur (34)	0.93 ± 0.04	0.93 ± 0.04	ns
Madhubani (15)	0.49 ± 0.03	0.54 ± 0.03	0.05
Coochbehar (10)	1.00 ± 0.11	1.19 ± 0.12	0.01
Dhanusha (41)	1.10 ± 0.21	1.12 ± 0.19	ns
Sunsari (32)	0.97 ± 0.0.06	0.94 ± 0.05	ns
Purnea (16)	0.51 ± 0.06	0.51 ± 0.06	ns
Malda (10)	1.06 ± 0.09	1.16 ± 0.09	0.08

After only three years, there was an increasing trend in SOC under CA practices as compared to the CT practice (Sinha et al., 2019). Changes in SOC are often only seen in the longer term following a change in tillage practice (Alvarez, 2005). However, the labile C fraction of soil organic matter, such as hot water soluble C, may provide early indication of potential long-term effects of CA practice on soil organic C as found in this study. Higher total N in soil under the CA practice may also lead to sequestration of organic C in these soils (Sinha et al., 2019). A study in Bihar over six years showed that CA based systems has higher total organic carbon compared to CT systems (Nandan et al., 2019), in particular increasing the longer persisting forms of carbon. Longer term monitoring of SRFSI sites under CA practices should be performed to validate these early findings.

2.3.2 Soil carbon source pools under different tillage regimes in West Bengal

Tillage method and crop type affect the total amount of carbon in the soil, and also the different pools or types of carbon present. Knowing how carbon pools change under different management practices provides valuable information on soil health. Soil analysis was conducted in Cooch Behar and Malda (West Bengal) after four years of long-term on-farm trials. This study was conducted as part of the SRFSI project in West Bengal only under a PhD project. It evaluated the effect of different tillage (zero-tillage (ZT) and conventional tillage (CT)) and cropping systems (rice-wheat (R-W) and rice-maize (R-M)) on soil carbon pools. Zero-tillage is a common practice included in conservation agriculture based systems.

Carbon pools are the different micro sources of carbon and represent a multitude of interrelated soil processes and functions (Awale et al., 2013). Carbon pools measured in this study included labile pool-I (LP-I), labile pool-II (LP-II), particulate organic matter carbon (POM-C), active or potassium permanganate oxidisable carbon (POXC), hot water extractable carbon (HWEC) and recalcitrant carbon (RC), which together make up Total Organic Carbon (TOC). These forms of carbon decompose at different rates. Some pools are resistant to break down (e.g. recalcitrant carbon) and therefore are unavailable as a microorganism food source. The remainder are more easily broken down. POM-C is a highly active fraction (>0.053 mm) and is directly available to micro-organisms. As such it plays a major role in soil aggregation and production of water extractable organic matter and serves as an energy source for soil microbial biomass (Gregorich et al., 2000; Six et al., 2000; Zotarelli et al., 2007). It is therefore important to understand the types of carbon present for better long-term crop management options, since soils with higher amounts of POM-C tend to be more fertile.

This study showed that the soil carbon pools significantly improved ($P<0.05$) in rice-maize cropping systems compared to rice-wheat systems, as shown in Figure 1, due to higher crop residue levels with maize compared to wheat. With regards to tillage management, ZT was superior to CT management for all carbon pools, even RC, although it was not statistically significant. Due to the slowdown of organic matter turn over in soil under ZT, the stable organic carbon fraction (recalcitrant pool) also increased. Previous studies also show that the addition of high amounts of recalcitrant compounds of the crop residue enhanced the stable SOM compounds quantity in soil under zero-tillage in wheat crop (Abril et al., 2013).

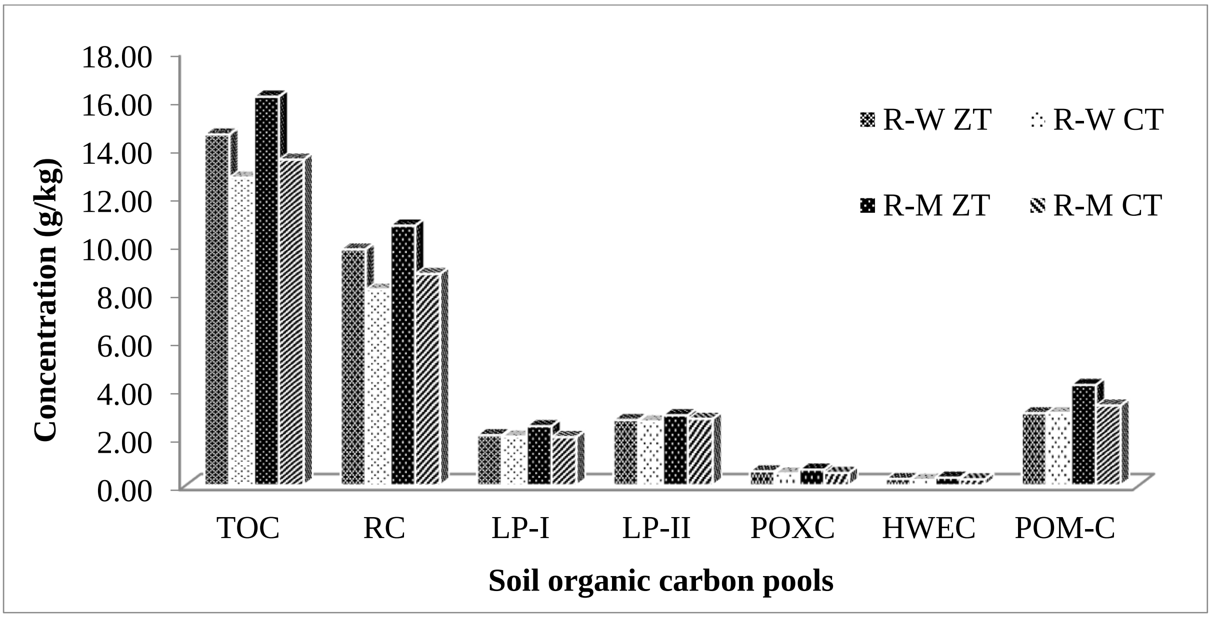

*Figure 2 Concentration of TOC and its source pools under different tillage and cropping systems (**R-W:** Rice-Wheat CS; **R-M:** Rice-Maize CS; **ZT:** Zero-tillage; **CT:** Conventional tillage; **LP-I**: Labile pool-I, **LP-II**: Labile pool-II, **RC:** Recalcitrant carbon, **TOC:** Total organic carbon, **POXC:** Permanganate oxidizable carbon, **HWEC:** Hot water extractable carbon, **POM-C:** Particulate organic carbon.*

Adoption of ZT in both districts improved the status of soil organic carbon and its pools in the upper layers (0 – 10cm) (Figure 2) because of continuous addition of crop residues and less disturbance of the soil surface during cultivation. It is clearly understood from this research that when ZT allows the crop residue to remain on the surface, it minimizes the contact between residue and soil which eventually reduces the decomposition rate, finally enriching the upper layer with a higher carbon source.

However, ZT practices failed to improve the lower depths (10 - 20 cm), because crop residues are left on the soil surface. In contrast, the CT practice improved all the pools in the lower layer (10 – 20cm) due to mechanical incorporation of residue. Dimassi et al. (2013) reported that the soil organic carbon stocks below the old plough layer (28 - 40 cm) were slightly greater in full inversion tillage (FIT) than in No-tillage (NT=ZT) treatment. A similar trend of CT enhancing the TOC content in the lower layer (10-20 cm) by 18 % compared to ZT was also reported by Zhu et al. (2014).

The depth-wise concentration of SOC (Figure 2) was higher in Malda sites which substantially increased its carbon pools compared to Cooch Behar sites. Malda district showed the highest amount of TOC because of higher crop yields and therefore greater amount of residue biomass application. Additionally, the soils in this district are rich in clay which resulted in higher carbon sequestration compared to other sandy loam soils studied in this experiment. All types of soil carbon pools except POM-C showed a strong significant correlation with TOC (R=>0.850, P<0.01) in both the districts.

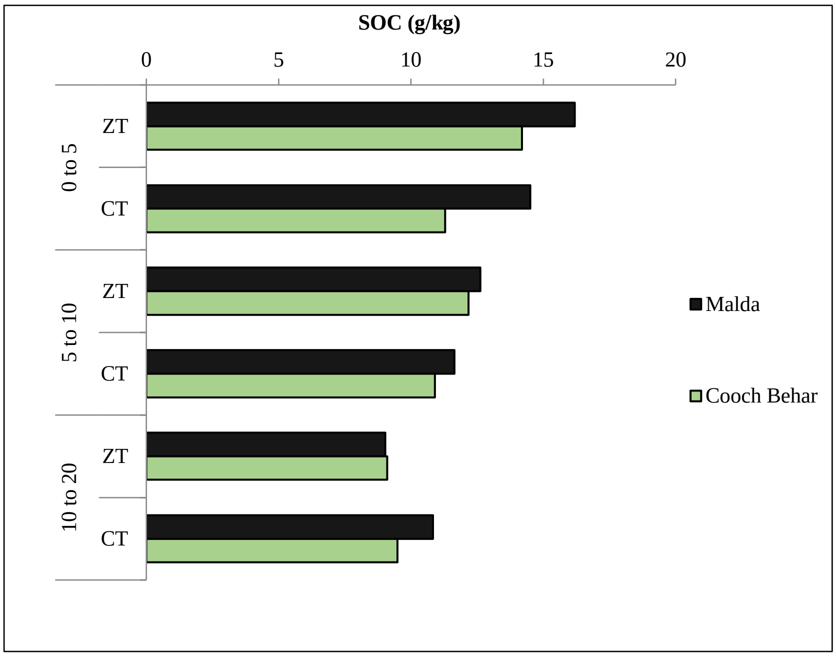

Figure 3 Status of soil organic carbon (SOC) at 3 soil depths under zero & conventional tillage systems (ZT & CT) in Malda and Cooch Behar districts.

Understanding the composition of carbon pools in a soil is important, as the proportion of each influences soil health and fertility. POM-C plays a major role in soil aggregation and production of water extractable organic matter, and also serves as a food for soil microorganisms. Soil microbes in turn play a vital role in transforming organic matter and nutrients within soil (Mooshammer et al., 2014). Addition of crop residue through conservation agriculture for a longer period improves the status of total organic carbon and its pools in the soil system and reduces CO_2 losses into the atmosphere by curbing the mineralization rate. To this end, analysing carbon pools and characterizing their interrelationships can improve our understanding of management effects on soil dynamics, as can repeating these types of experiments in different locations across the EGP.

2.4 Profitable climate smart agri-business opportunities

2.4.1 Improved farm level profitability

In addition to being resource efficient and reducing input related emissions, CA farming systems were also demonstrated to be more profitable for farmers. Table 12 shows system level gross margins on a per hectare basis, that is the total income received less the variable costs associated with production. For all cropping systems, using CA practices increased gross margins by 17% – 96% due to reduced input costs associated with these systems. Lowest increases of 17% were found for Rice-Maize and Rice-Wheat-Jute systems, while CA Rice-Rice systems almost doubled profits compared to conventional tillage. When Rice-Rice systems diversified in the rabi season to a different crop type, increased profitability ranged from 47% – 168%.

Table 12 Effects of CASI techniques on cropping system gross margin (AUD$.ha^{-1}) for cropping systems in the EGP (Gathala, n.d.-a). *RR Rice-Rice; RW Rice-Wheat; RM Rice-Maize; RL Rice-Lentil; RWMb Rice-Wheat-Mungbean; RWJ Rice-Wheat-Jute.*

Treatment	**Gross margin (AUD$/ha)**					
	RR	**RW**	**RM**	**RL**	**RWMb**	**RWJ**
T1 (Conventional)	1,084	1,260	2,423	1,948	1,360	2,492
T2 (Partial CASI)	1,972	1,480	2,708	2,278	1,781	2,908
T3 (Partial CASI)	2,271	1,656	2,896	2,386	2,044	2,762
T4 (Full CASI)	2,126	1,632	2,937	2,313	1,921	3,042
Mean change in net income compared to conventional tillage (T1)	96%	26%	17%	19%	41%	17%
Mean change in net income compared to conventional RR systems		47%	163%	115%	77%	168%

Separate analysis was conducted on increases in returns to different categories of households, including female, male and all households. Increases in returns to female headed households ($/ha) were similar to those for all/male headed households. In one dataset covering a range of locations and cropping systems, the average increase in gross margin was $468/ha for all households compared to $461 for female headed households; in some cases returns are larger for women headed than for male headed/all households.

2.4.2 Climate smart business opportunities

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

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

In West Bengal India, Farmers Club/Producer Organisations are acting as a linking mechanism between farmers and markets, government programs, financial institutions, research, NGOs and input suppliers research, providing training and associated CA services. In Malda, the Kalinaga Vidyanandnagar Club is linked with the state Department of Agriculture for seed certification, and their lentil and wheat seed production contributes a significant portion of the district's quality seed. The benefit of the FC and FPO model is that they are embedded and supported by government policy initiatives. The introduction of CA techniques has initiated additional income revenue streams for existing groups. Some also act as machinery distributers and repairs and maintenance, such as the Satmile Satish Club in Cooch Behar. The SSC has also recently started charging for agricultural training services, and they find that farmers and service providers are willing to pay as they see they are receiving quality services and inputs.

In West Bengal, the mechanical rice transplanter is becoming popular due to the lower labour requirements for crop establishment. This technique requires rice seedlings to be grown in specific mats, that are then fed into the machine. To work efficiently, service providers who sell these services need to be able to access the right varieties grown in mats of the right format, at the right growth stage for transplanting. Several women's Self Help Groups (SHG) have started to produce seedlings in mats to fill this gap. For example, in Cooch Behar the Mukta SHG are producing rice seedlings as a group of twelve women. Each season, they spend two months preparing the seedlings for sale. It costs 250 Rs to prepare around 25 trays for one bigha. They sell the 25 trays for 500-600 Rs/bigha. In Rabi season 2019, they had produced enough seedling trays for 700 bigha, while in kharif season 2018 enough to cover 1,000 bigha. This is a profit of AUD $5,100 - $7,150 per kharif season between the group, or $425 - $595 per family. In the rabi season, around $3,580 - $5,000 or $300 – $415 per family. As well as providing an additional income stream to support household food and education, the women also talked about feeling more confident in being part of a group, and having funds of their own.

3 Modelled impacts of farming system change

The APSIM model has been parameterised to explore the effects on yield (grain and biomass; kg/ha), profitability ($/ha), water productivity ($/mm irrigation water applied), energy productivity ($/litre of fuel used) and labour productivity ($/person-day) for CA and conventional (CT) crop management systems in different locations across the EGP.

The start and end date of the monsoon is highly variable and likely to become more so under climate change. This effects the time at which farmers can establish the rabi (winter) crop. The APSIM model has been used to explore the effect of planting dates for a range of crops in a range of locations and using this information to develop a decision support tool (DST) for farmers and extension workers that can reduce risks associated with yield penalties associated with date of planting. DST allows farmers to compare crop performance in terms of crop yields, gross margins, water productivity, energy productivity and labour productivity. Modelled results show that at most locations wheat is much more negatively affected by late planting than maize, although it was very variable with different locations and different crops; rainfall and temperature patterns are variable across the EGP, demonstrating that location specific recommendations are required.

APSIM modelling shows a clear value in retaining crop residue, with impacts on soil organic carbon and long term maize yields. For example, simulation of a 35-year rice-maize rotation in Rajshahi, Bangladesh shows that when systems maintain 100% residue retention compared to 0%, yield is increased by 36% (7.5 t/ha compared to 5.5 t/ha); and soil organic carbon is increased by 150% (1.5% compared to 0.6% in the top 0 – 15cm). Similar results were measured in West Bengal with improved status of soil organic carbon in the upper layers (0 – 10cm).

The APSIM model used as part of SRFSI is a valuable resource as a well-tested model which can contribute to further research analyses to explore how CASI approaches compare with traditional practices under future climate scenarios in terms of food, energy and water aspects; how future climate conditions affect rabi crop choices; and what are the optimum residue retention rates that account for trade-offs between long term benefits for soil health and crop production versus a fuel and fodder source.

4 Scaling sustainable farming systems

4.1 Impacts of current adoption

In total, up to 91,000 households have adopted CASI technologies, with more than 200,000 people exposed to these new techniques through field days, training and other project and partner activities as reported by partner organisations. The most widely adopted technologies include ZT wheat, maize and mustard, pulses, unpuddled transplanted rice in the boro season using a mechanised transplanter, and direct seeded rice. Table 13 contains a summary of adoption of various CASI technologies between May 2014 and July 2019.

In total, the adoption of these technologies has covered 60,436 hectares, generated an additional $24 million for smallholder farmers, saved 12,000 ML of water from being pumped, and reduced emissions associated with crop inputs by 11,000 tonnes CO_2-e (Table 14).

Table 13 Use of CASI technologies between May 2014 and October 2018.

	Extent		Impacts		
Major Activities[1]	**No. households**	**Area covered (ha)**	**Net profit ($AUD)**	**Irrigation water use (ML)**	**CO_2-e emission (t)**
ZT Maize[2]	8,153	4,979	$ 1,587,300	- 1,302	- 477
ZT Wheat	10,909	5,026	$ 1,061,400	- 1,440	- 665
Direct Seeded Rice	5,099	1,847	$ 418,300	- 399	- 237
UPTR Kharif Rice	274	72	$ 16,600	- 5	- 9
UPTR Boro Rice	6,909	4,084	$ 1,844,100	- 4,614	- 824
Pulse[3]	9,036	4,098	$ 1,725,400	- 2,259	- 227
ZT Mustard	2,364	755	$ 170,500	- 105	- 110
ZT/ST Jute	681	101	$ 600		- 6
Intercropping	729	48	$ 141,500	- 5	- 2
Long-term trials[4]	343	315	$ 122,100	- 21	- 40
Cropping systems	191	22	$ 8,500	- 3	- 3
Validation	170	105	$ 24,500	- 19	- 10
Total	**44,858**	**21,450**	**$ 7,120,790**	**- 10,160**	**- 2,605**

[1]Excludes some activities which are not CASI such as disk harrow or cultivator tillage, zinc rice, improved seed, herbicide management with CT etc.; ZT is Zero Tillage; UPTR is Unpuddled Transplanted Rice; ST is Strip Tillage. [2]Includes relay lentil and other ZT legumes. [3]Long-term trials on mustard was in Malda district, this data used for both Bangladesh and India. [4]Includes different systems like rice-maize, rice-wheat, rice-lentil, rice-wheat-mungbean etc. and the production cost and net profit change (CASI over CT) per hectare were based on the average of different systems of long-term trials. 1 AU$= 58.66 BDT; 1 AU$= 80.57 NRP and 1 AU$= 50.47 INR (the exchange rate of June 2015 was used for consistency).

Table 14 Scale of use of CASI and impact on economics, energy use and emissions as a result of SRFSI scaling intervention (2015 - 2019).

	Indicator	**No.**	**Average change in CASI over CT (ha^{-1})**	**Total**
Scale	No. farmers reached by project activities and convergence	219,192		
	No. farming households using CASI techniques	91,219		
	Area covered by CASI techniques (ha)	60,436		
Impact	Saving in production cost (AU$)*		-233	-14,000,000
	Additional net income (AU$)		395	24,000,000
	Irrigation water saving (ML)		-0.2	-11,926
	Energy use saving (GJ)		-3	-189,000
	Additional Net energy produced (GJ)		22	1,309,000
	CO_2-e GHGs mitigated (t)		-0.19	-11,000

* BDT58.66, 50.47 INR, and 80.57 NPR, respectively per AU$.

The results above give the current emissions reductions for the 91,219 farmers who have already adopted CA on their farms. This number represents between 0.03 - 6% of farmers in the project areas (Table 15), and 0.14% of farmers across the whole of the EGP.

Table 15 Proportion of farmers using CASI approaches in project locations.

Country	**Project location**	**No. farming households using CASI**	**Total no. farming households in District**	**% farmers currently using CASI**
India – West Bengal	Cooch Behar	41,518	687,000	6.04%
	Malda	24,515	866,000	2.83%
India – Bihar	Purnea	13,158	646,000	2.04%
	Madhbhani	246	898,000	0.03%
Bangladesh	Rangpur	5,304	720,000	0.74%
	Rajshahi	2,922	633,000	0.46%
Nepal	Sunsari	754	162,000	0.47%
	Dhanusha	43	138,000	0.03%

4.2 Regional Implications

4.2.1 Potential area of influence

There are 180 districts within the boundaries of the region known as the EGP, covering 30 million hectares of land and home to some 450 million people. Within this region, there is also huge variability in terms of social structure, farm types, cropping systems, land topography, crop yields, infrastructure, market networks, local policies and governance. The work undertaken within the ACIAR SDIP program covered eight districts across four states and three countries and is representative of many of the farming systems in the EGP. The region was divided into six major farming system zones based on dominant cropping systems, crop yields, access to irrigation, availability of mechanization services, and livestock holdings (Figure 4) (Gathala et al., Forthcoming).. Existing biophysical, socio-economic, and institutional settings are used to analyse the potential impacts of converting relevant areas of these farming system zones to CASI and/or diversifying cropping systems.

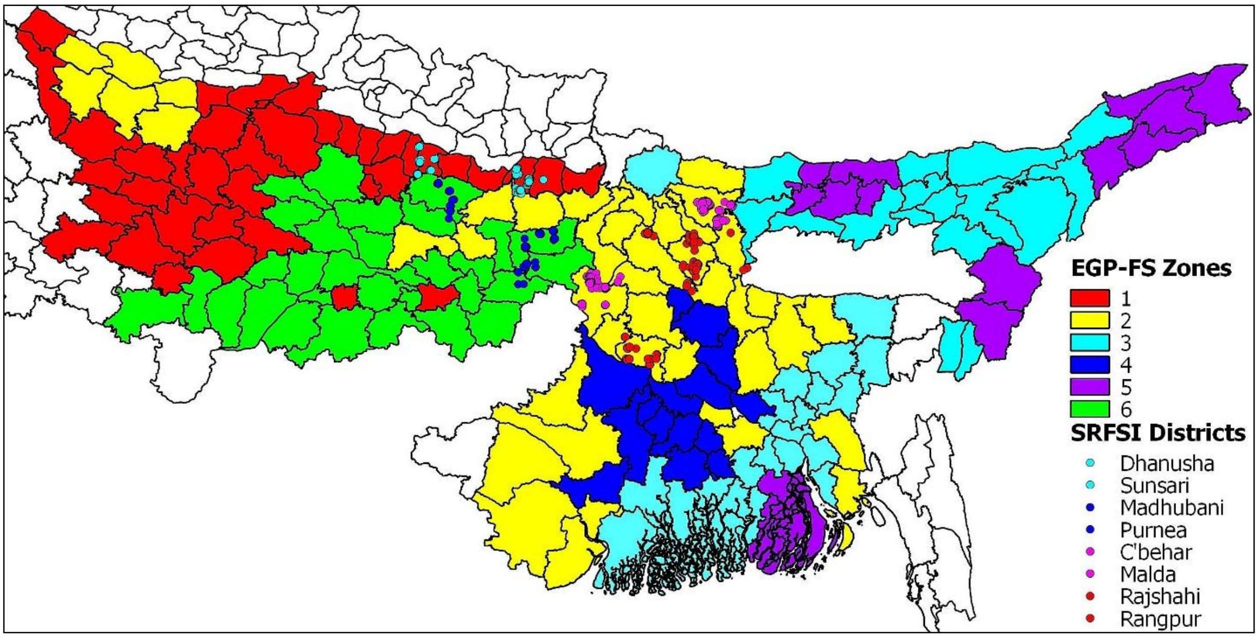

Figure 4 Farming systems zones in the EGP. SRFSI districts are represented by coloured points.

Zone 1 is dominated by rice-wheat cropping systems (54% of cropped area). The zone is characterized by poor soil and land management, poor road networks, a lack of availability of quality inputs and output markets, low intervention and thus poor adoption of modern technologies. Small and marginal farm households with fragmented landholdings make up 73% of farming households. Although there are high rates of irrigation (84% of cropping area), irrigation is costly due to a heavy reliance on diesel pumping. zone consists of 37 districts from Nepal, Eastern UP, and Bihar with a total cultivable area of 5.38 million ha. There is great scope for crop intensification by converting summer fallow provided that alternate irrigation infrastructure is developed to allow affordable access to groundwater (e.g. electrification, solar energy).

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

Zone 3 is dominated by rice-rice systems. It is characterized by low laying landscape in the catchment of the Brahmaputra and Meghna rivers in Bangladesh and Assam with high climatic shocks, low mechanization due to poor connectivity and infrastructure, and less scope for cropping intensification due to low lying land with excess moisture. However, it has a good coverage of short duration oilseed crops. 80% of farming households are categorized as small and marginal, and suffer from poor market access. This zone consists of 35 districts from Bangladesh, Assam and West Bengal, with a total cultivable area of 4.8 million ha. There is potential to promote integrated fish and rice farming systems, improved/hybrid high yielding varieties and deep water tolerant rice varieties, and suitable short duration oilseed and pulses to significantly improve food security and livelihoods for farmers in this zone.

Zone 4 is dominated by rice-rice cropping systems, present on 64% of net sown area, with rice-wheat under 11% of land. This zone has the highest cropping intensity in the EGP at 237%, and the highest yields of rice, wheat and maize. This zone is fairly well mechanized with developed markets and 69% of the cultivable area is under irrigation, although arsenic contamination of groundwater is problematic. This zone consists of 15 districts in Bangladesh (12) and West Bengal (3), and has 2.29 million ha of cultivable land. There is high potential to promote CASI technologies for improved productivity of wheat and maize.

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

Zone 6 is dominated by rice-wheat cropping systems (41% of net sown area), with rice-maize an emerging system that is gaining popularity. The zone is characterized by poor farming households, high rates of share cropping, complex social structures and poor coordination among existing institutions and government schemes. There is access to irrigation on 56% of cropped area, but it is uncertain and costly. Soil acidity is a problem that further constrains yields and options for diversification. Wheat productivity is low due to late sowing, poor mechanization and land fragmentation. This zone consists of 30 districts (28 of Bihar and 2 of Eastern UP) and has a total cultivable area of 5.5 million ha. This zone is well mechanized for tillage which is very resource intensive, and so there is potential to promote other mechanized CASI practices.

4.2.2 Regional impacts of different levels of adoption

Long-term on-farm trial results have been used to estimate the implications associated with the expansion of area using CASI technologies. Currently R-R, R-W, R-M and R-L systems are practised in approximately 6.5, 6.2, 1.0 and 0.7 million hectares (mha) respectively across 188 districts in the EGP. Converting a proportion of these systems to full CASI use would have significant effects on system productivity, profitability at the farm scale, and resource use (Table 16). For example, converting 10% of the area of these systems would increase productivity by 958,000 tonnes, generate $1,041 million (AUD) in farm profits, reduce irrigation water use by 1,096 GL, reduce energy use by 6 PJ and reduce carbon emissions by 371,000 tonnes of CO_2-e. Increasing use to 50% of the area of these systems would increase productivity by almost 5 million tonnes, generate more than $5 billion (AUD) in farm profits, reduce irrigation water use by 5,480 GL, reduce energy use by over 30 PJ and reduce carbon emissions by almost two million tonnes of CO_2-e. More details for the partial and full CASI systems conversion are found in Appendix 1.

Table 16 Impact of converting 5% – 50% of the Rice-Rice, Rice-Wheat, Rice-Maize and Rice-Lentil systems in the EGP to full CASI systems.

% Conversion to CASI	**Area in EGP (mha)**	**Area under CASI (mha)**	**System rice equivalent productivity ('000 tonne)**	**Gross margin ($ m AUD)**	**Total Irrigation water use (GL)**	**Energy use (PJ)**	**CO_2 equivalent emission ('000 tonne)**
5%	14.4	0.7	479.1	520.8	- 548.1	- 3.0	- 185.3
10%	14.4	1.4	958.2	1,041.7	- 1,096.2	- 6.0	- 370.7
20%	14.4	2.9	1,916.4	2,083.3	- 2,192.3	- 12.1	- 741.3
50%	14.4	7.2	4,790.9	5,208.3	- 5,480.8	- 30.1	- 1,853.4

In addition to the use of CASI technologies, system diversification and optimization also plays an important role in increasing farm level productivity and profitability, reducing water and energy requirements, and decreasing greenhouse gas emissions (Table 17). For example, if 10% of the RR area was converted to RM, then productivity would be further increased by 747,000 t, farm level profits would increase by $378 million (AUD), irrigation water requirements would be reduced by 4,610 GL, energy requirements would be reduced by 3.1 PJ, and CO_2-e emissions would be reduced by 291,000 tCO_2-e. Replacing 50% of the RR system with CASI based RM system would mean productivity would be further increased by over 3.5 million t, farm level profits would increase by over $2 billion (AUD), irrigation water requirements would be reduced by 23,000 GL, energy requirements would be reduced by 15 PJ, and CO_2-e emissions would be reduced by over 1.7 million tCO_2-e. These results also highlight that in some cases, diversifying systems can have a negative impact on profitability, for example converting from RR to RL systems.

Table 17 Impacts of converting to CASI and diversifying Rice-Rice systems to Rice-Maize (RM), Rice-Lentil (RL) or Rice-Wheat-Jute (RWJ).

Scenario - % conversion	Diversification and intensification option	Area under CASI ('000 ha)	System rice equivalent productivity ('000 tonne)	Gross margin ($ m AUD)	Total Irrigation water use (GL)	Energy use (PJ)	CO_2 equivalent emissions ('000 tonne)
5%	RM	0.33	374	189	- 2,305	-1.5	- 146
5%	RL	0.33	343	- 12	- 2,706	-6.0	- 391
5%	RWJ	0.33	635	218	- 2,218	-1.9	- 178
10%	RM	0.65	747	378	- 4,610	-3.1	- 291
10%	RL	0.65	685	- 24	- 5,412	-11.9	- 783
10%	RWJ	0.65	1,269	436	- 4,436	-3.7	- 356
20%	RM	1.30	1,495	756	- 9,220	-6.1	- 583
20%	RL	1.30	1,370	- 47	- 10,824	-23.8	- 1,566
20%	RWJ	1.30	2,539	872	- 8,872	-7.5	- 712
50%	RM	3.26	3,737	1,891	- 23,051	-15.3	- 1,457
50%	RL	3.26	3,426	- 118	- 27,059	-59.5	- 3,914
50%	RWJ	3.26	6,347	2,180	- 22,179	-18.7	- 1,779

Considering the crop that is being replaced is important, as not all diversification options have the same outcomes. Diversification within RW systems is shown in Table 18. Productivity and farm level profitability are increased in all scenarios, ranging between 839,000 tonnes and $95 million AUD (5% area under RWMb) to 13 million tonnes and over $4 billion AUD (50% area under RWJ). However, these diversification patterns also increase resource use including irrigation water up to 2,216 GL (50% RWJ), energy consumption by 23 PJ (50% RWMb) and carbon emissions by over 1 million tonnes (50% RWJ). When diversifying from RW systems, RL systems are the only option that do not increase resource use. These systems can reduce irrigation water by 2,447 GL, energy use by 24 PJ and carbon emissions by over 1 million tonnes. More details of these diversification options are found in Appendix 2.

Table 18 Impacts of converting to CASI and diversifying Rice-Wheat systems to Rice-Maize (RM), Rice-Lentil (RL) or Rice-Wheat-Mungbean (RWMb) or Rice-Wheat-Jute (RWJ).

Scenario	**Diversification and intensification option**	**Area under CASI (m ha)**	**System rice equivalent productivity ('000 tonne)**	**Gross margin ($ m AUD)**	**Total Irrigation water use (GL)**	**Energy use (PJ)**	**CO_2 equivalent emissions ('000 tonne)**
5%	RM	0.31	1059	380	138	1.9	97
5%	RL	0.31	1029	188	-245	-2.4	-137
5%	RWMb	0.31	839	95	70	2.3	114
5%	RWJ	0.31	1308	408	222	1.5	67
10%	RM	0.62	2118	760	277	3.7	195
10%	RL	0.62	2059	376	-489	-4.7	-275
10%	RWMb	0.62	1679	191	140	4.7	228
10%	RWJ	0.62	2617	816	443	3.1	133
20%	RM	1.24	4236	1521	553	7.4	390
20%	RL	1.24	4117	753	-979	-9.5	-549
20%	RWMb	1.24	3358	381	281	9.3	457
20%	RWJ	1.24	5233	1632	886	6.1	267
50%	RM	3.11	10590	3802	1383	18.5	974
50%	RL	3.11	10293	1882	-2447	-23.7	-1373
50%	RWMb	3.11	8395	953	702	23.3	1142
50%	RWJ	3.11	13083	4079	2216	15.3	666

These results have important implications for policy makers and planners, since relatively small investments in promoting CASI technologies and diversification of farming systems would result in increasing food security and sustainable resource use in the EGP. They also highlight the trade-offs where in some cases converting existing systems results in higher resource consumption, as is the case with most of the options studied for RW systems.

5 Policy drivers and influence

5.1 Interacting policy drivers

Rice based cropping systems result in a high level of crop residue after harvest that must be managed before a subsequent crop can be grown. Across India, around 90 million tonnes of crop residues are burnt annually, with rice (43%) and wheat (21%) straw both major residue sources (Bhuvaneshwari, Hettiarachchi, & Meegoda, 2019). Burning of crop residues emitted 141.15 Mt of CO_2 in 2008–09. It is estimated that in the NW Indian states of Punjab and Haryana, up to 23 million tonnes of rice crop residue is burnt each year in the narrow timeframe available for planting the subsequent crop, since combine harvesters were introduced in the 1980s (Balwinder-Singh, McDonald, Srivastava, & Gerard, 2019). This contributes to increasingly detrimental effects on atmospheric pollution and greenhouse gas emissions. Stubble burning is banned by the National Green Tribunal, but farmers generally disregard the rules because the alternative cost of labour or equipment for management is thought to be too high. Zero till crop establishment methods, including the Happy Seeder, are an option to allow a subsequent crop to be sown into standing rice stubble. The project *Value chain and policy interventions to accelerate the adoption of Happy Seeder zero tillage in rice-wheat farming systems across the Gangetic Plains* was undertaken to identify the barriers and opportunities to adoption of zero-till technology, and to inform policy interventions and programs. The adoption of zero till crop establishment methods could reduce CO_2 emissions significantly by eliminating the need for stubble burning in the EGP.

An interesting analysis by Balwinder-Singh et al (2019) highlights the interactions between groundwater management policies and increased burning of crop residues. In 2009, two groundwater acts were passed prohibiting transplanting of rice before 20 June, with the aim of reducing groundwater use for rice production before the monsoon had commenced. The effect of this, while achieving the reduction in groundwater use, has been to delay harvest by several weeks, which concentrates burning in the first two weeks of November as farmers try to quickly plant wheat after rice harvest. This has resulted in a 39% higher peak fire intensity at a time when temperatures are lower and winds weaker than the previous situation, partially explaining why air pollution has worsened in the past decade, particularly in Delhi. The tensions between managing groundwater conservation and air pollution should rely on new technologies like the Happy Seeder, as well as policy incentives associated with energy that result in full pricing of electricity. There are lessons for the EGP, where water resources are not constrained, and crop residues are more highly valued for livestock production (Balwinder-Singh et al., 2019).

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

5.2 Aligning with government schemes and programs that support adaptation to climate change

In several cases ACIAR SDIP partners have succeeded in influencing government programs either through direct access to additional funds to promote CASI, or in having CASI machinery included in subsidy schemes where it was previously not included.

Bihar: The Central Government, through the Bihar State Government, has a program to improve climate resilience, the National Initiative on Climate Resilient Agriculture (NICRA). Bihar Agricultural University (BAU) have been awarded 18 million Indian Rupees (AUD $350,000) to promote climate resilient technologies and upgrade water harvesting structures. As part of this program, BAU will use the funds to promote CASI technologies to improve resilience to climate change. This funding was awarded to BAU due to their demonstration of the effectiveness of CASI technologies in Bihar as a method for farmers to improve resilience to climate change.

Based on successful demonstration of CASI technologies, BAU have lobbied the Bihar State Government to include CASI machinery in subsidies, and now relevant machinery (zero till machines, laser leveller, rice transplanters) is eligible for 50% subsidy on purchase price. Additionally, farmers who use drill seeding to establish their rice crop are eligible to claim 5,000 INR/ha (AUD $100) in the form of repayment for purchase of inputs such as seed, fertiliser and agrichemicals. There is no limit on the area that can be claimed for. This success in leveraging additional funding can be attributed in part to the success of field trials and farmer adoption of CASI technologies under the SRFSI project.

West Bengal: Farm mechanisation schemes in West Bengal support small and marginal farmers to purchase small farm implements, as well as rural entrepreneurs to set up Custom Hiring Centres (CHC) of farm machinery. These government policies have been in place since 2012 (farmers) and 2014 (CHC). The government aims to reduce reliance on scarce manual labour, reduce production costs and improve productivity through more timely practices, including utilising narrow windows between consecutive crops.

For rural entrepreneurs to set up a CHC, the aim is to encourage the use of different types of machinery among small and marginal farmers through hiring of services from CHC. CHC are set up as end-to-end machinery portfolios (i.e. land development to residue management), with average coverage targeted at 10 ha/day and 300 ha per season. A set of compulsory machinery for CHCs is designed to promote new technology and avoid environmental hazards associated with straw and stubble management. Due to lobbying from SRFSI partners in West Bengal, and demonstration of the success of CA approaches, half of the machines on the list of six are based on CA principles. The list comprises tractors that must be accompanied by a trolley or multi-crop planter, and six additional machines, of which each CHC must have four. These include (1) power tiller/power weeder; (2) combine harvester; (3) self-propelled rice transplanter; (4) ZT multi-crop planter; (5) multi-crop thresher; (6) Happy Seeder. This means that all CHC will have at least one CA machine available and demonstrates the commitment of the Government of West Bengal in supporting CA scaling.

Bangladesh: The Department of Agriculture in Bangladesh are supporting Mechanisation Hubs which operate as a custom service centre. These centres contain machinery such as power tillers, mini combine harvesters, reapers and rice transplanters. Several of these machinery options support CASI services.

6 Conclusions and gaps to be addressed

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

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

There are several elements associated with climate change adaptation and mitigation that have not been measured, and which should be pursued in the future. This includes:

- Tracking changes in fertilizer use associated with CASI approaches to see if fertilizer use is reduced, with a focus on nitrogen fertilizer.
- Tracking the performance of CASI approaches under extreme weather events.
- Measurement and/or simulation of direct emissions from individual fields and comparisons to the aggregate approach used here.
- Longer term monitoring of soil carbon trends under CA based systems and during transitions to different farming systems with alternate crop rotations.
- Determining the flexibility farmers have to alter sowing dates in response to climate variability, and identify the risks and benefits of this approach.

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Appendix 1: Impact of using CASI technologies

Table 19 Impact of using CASI systems (full or partial), considering 5% of total area is converted after five years.

System	CASI Option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 1 (if 5% area covered with CASI after 5 years)											
RR	Partial	6.51	325.5	386.7	- 345.8	- 345.8	- 938.4	- 117.7	289.1	- 8.6	- 62.6
	Full	6.51	325.5	333.0	- 455.3	- 455.3	- 1,674.0	- 194.5	362.7	- 18.6	- 105.4
RW	Partial	6.22	311	72.1	- 75.9	- 61.6	- 597.7	- 43.1	68.4	- 5.8	- 38.7
	Full	6.22	311	94.1	- 78.3	- 56.3	- 1,103.1	- 84.6	119.4	- 15.3	- 67.0
RM	Partial	1	50	18.8	- 10.2	- 16.7	- 23.6	- 6.9	14.2	- 1.3	- 5.7
	Full	1	50	24.0	- 14.4	- 14.3	- 167.0	- 14.5	24.7	- 3.0	- 9.3
RL	Partial	0.7	35	21.3	-	- 14.1	- 41.6	- 3.3	11.5	- 0.1	- 2.6
	Full	0.7	35	27.9	-	1.4	- 69.9	- 5.7	14.1	- 1.3	- 3.7
Total	**Partial**	**14.43**	**722**	**499.0**	**- 431.9**	**- 438.2**	**- 1,601.3**	**- 171.0**	**383.2**	**- 15.7**	**- 109.6**
	Full	**14.43**	**722**	**479.1**	**- 548.1**	**- 524.6**	**- 3,014.0**	**- 299.3**	**520.8**	**- 38.2**	**- 185.3**

Table 20 Impact of using CASI systems (full or partial), considering 10% of total area is converted after five years.

System	CASI Option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 2 (if 10% area covered with CASI after 5 years)											
RR	Partial	6.51	651	773	- 692	- 692	- 1,877	- 235	578	- 17	- 125
	Full	6.51	651	666	- 911	- 911	- 3,348	- 389	725	- 37	- 211
RW	Partial	6.22	622	144	- 152	- 123	- 1,195	- 86	137	- 12	- 77
	Full	6.22	622	188	- 157	- 113	- 2,206	- 169	239	- 31	- 134
RM	Partial	1	100	38	- 20	- 33	- 47	- 14	28	- 3	- 11
	Full	1	100	48	- 29	- 29	- 334	- 29	49	- 6	- 19
RL	Partial	0.7	70	43	-	- 28	- 83	- 7	23	- 0	- 5
	Full	0.7	70	56	-	3	- 140	- 11	28	- 3	- 7
Total	**Partial**	**14.4**	**1,443**	**998**	**- 864**	**- 876**	**- 3,203**	**- 342**	**766**	**- 31**	**- 219**
	Full	**14.4**	**1,443**	**958**	**- 1,096**	**- 1,049**	**- 6,028**	**- 599**	**1,042**	**- 76**	**- 371**

Table 21 Impact of using CASI systems (full or partial), considering 20% of total area is converted after five years.

System	CASI Option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 3 (if 20% area covered with CASI after 5 years)											
RR	Partial	6.51	1,302	1,547	- 1,383	- 1,383	- 3,754	- 471	1,156	- 34	- 250
	Full	6.51	1,302	1,332	- 1,821	- 1,821	- 6,696	- 778	1,451	- 75	- 422
RW	Partial	6.22	1,244	288	- 303	- 246	- 2,391	- 172	273	- 23	- 155
	Full	6.22	1,244	377	- 313	- 225	- 4,412	- 339	478	- 61	- 268
RM	Partial	1	200	75	- 41	- 67	- 94	- 28	57	- 5	- 23
	Full	1	200	96	- 58	- 57	- 668	- 58	99	- 12	- 37
RL	Partial	0.7	140	85	-	- 57	- 166	- 13	46	- 0	- 10
	Full	0.7	140	112	-	5	- 280	- 23	56	- 5	- 15
Total	**Partial**	**14.4**	**2,886**	**1,996**	**- 1,727**	**- 1,753**	**- 6,405**	**- 684**	**1,533**	**- 63**	**- 438**
	Full	**14.4**	**2,886**	**1,916**	**- 2,192**	**- 2,098**	**- 12,056**	**- 1,197**	**2,083**	**- 153**	**- 741**

Table 22 Impact of using CASI systems (full or partial), considering 50% of total area is converted after five years.

System	CASI Option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 4 (if 50% area covered with CASI after 5 years)											
RR	Partial	6.51	2,604.0	3,867.5	- 3,458.0	- 3,458.0	- 9,384.2	- 1,176.8	2,890.7	- 85.7	- 625.6
	Full	6.51	2,604.0	3,330.2	- 4,553.5	- 4,553.5	- 16,740.5	- 1,945.5	3,626.9	- 186.3	- 1,053.8
RW	Partial	6.22	2,488.0	721.2	- 758.7	- 615.8	- 5,977.4	- 430.5	683.5	- 58.1	- 387.2
	Full	6.22	2,488.0	941.4	- 782.9	- 562.9	- 11,031.2	- 846.5	1,194.1	- 153.4	- 669.9
RM	Partial	1	400.0	188.1	- 101.9	- 166.5	- 235.5	- 69.0	142.4	- 12.6	- 57.2
	Full	1	400.0	240.0	- 144.5	- 143.2	- 1,669.5	- 144.8	246.8	- 29.6	- 93.1
RL	Partial	0.7	280.0	213.2	-	- 141.4	- 415.8	- 33.3	115.4	- 0.8	- 25.6
	Full	0.7	280.0	279.3	-	13.7	- 699.3	- 56.7	140.6	- 13.0	- 36.5
Total	**Partial**	**14.4**	**5,772.0**	**4,990.0**	**- 4,318.7**	**- 4,381.7**	**- 16,012.9**	**- 1,709.7**	**3,832.0**	**- 157.2**	**- 1,095.6**
	Full	**14.4**	**5,772.0**	**4,790.9**	**- 5,480.8**	**- 5,246.0**	**- 30,140.4**	**- 2,993.4**	**5,208.3**	**- 382.4**	**- 1,853.4**

Appendix 2: Impact of using CASI and diversifying farming systems

Table 23 Impact of using CASI and diversifying farming systems, considering 5% of total area of R-R or R-W systems is diversified after five years.

Current system	Diversification and intensification option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 1 (if 5% RR area diversified with potential systems after 5 years)											
RR	RM	6.51	325.5	373.7	-2,305.1	-2,526.5	-1,531.8	-148.9	189.1	-5.6	-145.7
RR	RL	6.51	325.5	342.6	-2,705.9	-3,808.1	-5,950.8	-288.9	-11.8	-12.2	-391.4
RR	RWJ	6.51	325.5	634.7	-2,217.9	426.7	-1,870.0	-65.0	218.0	9.0	-177.9
RW	RM	6.22	311.0	1,059.0	138.3	266.5	1,852.0	64.3	380.2	2.8	97.4
RW	RL	6.22	311.0	1,029.3	-244.7	-958.0	-2,370.1	-69.4	188.2	-3.5	-137.3
RW	RWMb	6.22	311.0	839.5	70.2	742.4	2,331.9	163.0	95.3	7.9	114.2
RW	RWJ	6.22	311.0	1,308.3	221.6	3,088.2	1,528.9	144.5	407.9	16.7	66.6
RR	**Mean**	**6.51**	**325.5**	**450.3**	**-2,409.6**	**-1,969.3**	**-3,117.5**	**-167.6**	**131.8**	**-2.9**	**-238.4**
RW	**Mean**	**6.22**	**311.0**	**1,059.0**	**46.3**	**784.8**	**835.7**	**75.6**	**267.9**	**6.0**	**35.2**

Table 24 Impact of using CASI and diversifying farming systems, considering 10% of total area of R-R or R-W systems is diversified after five years.

Current system	Diversification and intensification option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M3)	Total input water use (m M3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 2 (if 10% RR area diversified with potential systems after 5 years)											
RR	RM	6.5	651.0	747.5	-4,610.1	-5,053.1	-3,063.6	-297.9	378.2	-11.2	-291.5
RR	RL	6.5	651.0	685.2	-5,411.9	-7,616.2	-11,901.6	-577.8	-23.7	-24.3	-782.8
RR	RWJ	6.5	651.0	1,269.3	-4,435.9	853.5	-3,740.0	-129.9	436.1	18.0	-355.8
RW	RM	6.2	622.0	2,118.1	276.6	533.1	3,704.0	128.6	760.5	5.6	194.8
RW	RL	6.2	622.0	2,058.6	-489.4	-1,915.9	-4,740.3	-138.8	376.5	-6.9	-274.7
RW	RWMb	6.2	622.0	1,678.9	140.4	1,484.7	4,663.8	326.1	190.7	15.8	228.5
RW	RWJ	6.2	622.0	2,616.7	443.1	6,176.5	3,057.8	289.1	815.8	33.5	133.3
RR	**Mean**	**6.5**	**651.0**	**900.7**	**-4,819.3**	**-3,938.6**	**-6,235.1**	**-335.2**	**263.5**	**-5.8**	**-476.7**
RW	**Mean**	**6.2**	**622.0**	**2,118.1**	**92.7**	**1,569.6**	**1,671.3**	**151.2**	**535.8**	**12.0**	**70.5**

Table 25 Impact of using CASI and diversifying farming systems, considering 20% of total area of R-R or R-W systems is diversified after five years.

Current system	Diversification and intensification option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 3 (if 20% RR area diversified with potential systems after 5 years)											
RR	RM	6.51	1,244.0	1,495.0	-9,220.2	-10,106.1	-6,127.2	-595.8	756.4	-22.3	-582.9
RR	RL	6.51	1,244.0	1,370.4	-10,823.7	-15,232.5	-23,803.2	-1,155.5	-47.3	-48.6	-1,565.7
RR	RWJ	6.51	1,244.0	2,538.6	-8,871.7	1,706.9	-7,480.0	-259.8	872.1	35.9	-711.7
RW	RM	6.22	1,244.0	4,236.2	553.2	1,066.1	7,408.0	257.2	1,520.9	11.3	389.6
RW	RL	6.22	-	4,117.1	-978.8	-3,831.9	-9,480.5	-277.6	753.0	-13.8	-549.4
RW	RWMb	6.22	3,255.0	3,357.8	280.7	2,969.4	9,327.5	652.1	381.4	31.7	456.9
RW	RWJ	6.22	3,255.0	5,233.4	886.2	12,352.9	6,115.5	578.2	1,631.5	66.9	266.6
RR	**Mean**	**6.51**	**1,244.0**	**1,801.3**	**-9,638.6**	**-7,877.2**	**-12,470.1**	**-670.4**	**527.1**	**-11.7**	**-953.4**
RW	**Mean**	**6.22**	**1,938.5**	**4,236.1**	**185.3**	**3,139.1**	**3,342.6**	**302.5**	**1,071.7**	**24.0**	**140.9**

Table 26 Impact of using CASI and diversifying farming systems, considering 50% of total area of R-R or R-W systems is diversified after five years.

Current system	Diversification and intensification option	Area in EGP mha in respective systems	Area under CASI ('000 ha)	System rice euivalent productivity ('000 tonne)	Total Irrigation water use (m M^3)	Total input water use (m M^3)	Energy use (m MJ)	Cost of production (m AUD)	Gross margin (m AUD)	Labor use (m persons)	CO2 equivalent emission ('000 tonne)
Scenario 4 (if 50% RR area diversified with potential systems after 5 years)											
RR	RM	6.51	3,255.0	3,737.4	- 23,050.6	- 25,265.3	- 15,318.0	- 1,489.4	1,891.0	- 55.9	- 1,457.3
RR	RL	6.51	3,255.0	3,425.9	- 27,059.4	- 38,081.2	- 59,507.9	- 2,888.8	- 118.4	- 121.6	- 3,914.1
RR	RWJ	6.51	3,255.0	6,346.6	- 22,179.4	4,267.3	- 18,700.0	- 649.5	2,180.3	89.8	- 1,779.2
RW	RM	6.22	3,110.0	10,590.5	1,383.1	2,665.3	18,520.1	643.0	3,802.3	28.2	974.1
RW	RL	6.22	3,110.0	10,292.9	- 2,447.1	- 9,579.7	- 23,701.3	- 694.1	1,882.5	- 34.6	- 1,373.4
RW	RWMb	6.22	3,110.0	8,394.5	701.8	7,423.6	23,318.8	1,630.3	953.5	79.1	1,142.3
RW	RWJ	6.22	3,110.0	13,083.5	2,215.5	30,882.3	15,288.8	1,445.4	4,078.8	167.3	666.5
RR	**Mean**	**6.51**	**3,255.0**	**4,503.3**	**- 24,096.5**	**- 19,693.1**	**- 31,175.3**	**- 1,675.9**	**1,317.6**	**- 29.2**	**- 2,383.5**
RW	**Mean**	**6.22**	**3,110.0**	**10,590.3**	**463.3**	**7,847.9**	**8,356.6**	**756.1**	**2,679.2**	**60.0**	**352.4**