Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India

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Small landholders can implement a range of climate-smart agricultural (CSA) practices and technologies, in order to minimize the adverse effects of climate change and variability, but their adoption largely depends on economic benefits associated with the practices. To demonstrate the potential economic benefits of CSA practices, we conducted a study with smallholder farmers in the Indo-Gangetic Plains (IGP) of India. Among the CSA practices and technologies including use of improved crop varieties, laser land levelling, zero tillage, residue management, site specific nutrient management, and crop diversification, a majority of the farmers prefer to use improved crop varieties, crop diversification, laser land levelling and zero tillage practice. We estimated the cost of adoption, change in yields and income for the implementation of three major CSA practices in rice–wheat system. The average cost of adoption were +1,402, +3,037 and –1,577 INR ha^{-1} for the use of improved crop varieties, laser land levelling and zero tillage respectively. Results show that farmers can increase net return of INR 15,712 ha^{-1} yr^{-1} with improved crop varieties, INR 8,119 ha^{-1} yr^{-1} with laser levelling and INR 6,951 ha^{-1} yr^{-1} with zero tillage in rice–wheat system. Results also show that the combination of improved seeds with zero tillage and laser land levelling technologies can further improve crop yields as well as net returns. The econometric analysis indicates that implementations of CSA practices and technologies in smallholder farms in the IGP of India, have significant impacts on change in total production costs and yield in rice–wheat system.

Keywords: Adoption, climate change, laser land levelling, rice–wheat system, zero-tillage.

Introduction

SMALLHOLDER farming dominates the agricultural landscape of India. More than 80% farmers in India are small landholders (SLs) having less than two ha farm size[1]. They contribute more than 50% of total agricultural output by cultivating 44% of agricultural land and support livelihood and food security of millions of people. SLs in Indo-Gangetic Plains (IGP) of India follow a diversified agricultural production system. Therefore, smallholder farmers constitute a key group requiring attention in agriculture to increase their productivity and income for reducing hunger and poverty in the IGP.

SLs face a number of challenges in producing food in a sustainable manner. Lack of agricultural inputs, low access to market, frequent pest and disease outbreaks, and other production and market risks, already are challenges for SLs in the IGP. Climate change and variability observed in the IGP region add further pressure on them. Although climate change affects both large and small farmers, many researchers argue that it affects SLs disproportionately, due to their low adaptive capacity[2–4].

Over the last 100 years, an increase of 0.4°C in annual average surface air temperature has been recorded in the Indian subcontinent, and by the 2050s, average temperature is expected to rise by 2–4°C (ref. 5). The spatial and seasonal variation in rainfall is also likely to increase in the coming decades. Historical trends show a noticeable increase in mean temperature and large variation in monsoon rainfall in India and IGP region. In recent years the impacts of these changes on Indian agriculture have been studied. Climate change is likely to reduce yields of most crops in long-term, and increased climatic variability could cause significant fluctuations in production in the short-run[6]. Recent studies on regional and global simulation models also indicate that a moderate increase in temperature will have significant negative impact on rice, wheat and maize yields in India[7–9]. Climate change may further worsen the agricultural production system in IGP region by increasing water scarcity, frequency and severity of floods, and declining soil carbon[10]. Impacts of frequent and severe droughts and floods on crop production in many parts of the region, have already been observed[11–13]. Therefore, the climate change and variability may lead to greater instability in food production and threaten the food security of millions of smallholder farmers in the IGP.

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Development of appropriate adaptation strategy under smallholder production condition is important to cope with the progressive climate change and variability. Several CSA practices such as cropping system improvement (e.g. crop rotation, diversification, improved varieties and integration of legumes), integrated nutrient management (e.g. green manure, compost and site specific nutrient management), resource conservation (e.g. minimum/zero tillage, keeping the land consistently covered with crop residues), precision water management (e.g. planting crops in bed, laser land levelling, mulching with crop residues) and agroforestry have been proposed for adaptation to climate change and variability. CSA is defined as an approach that promotes sustainable increase in agricultural productivity and income, adapting and building resilience to climate change and reducing greenhouse gas emissions (GHGE)[14]. Many empirical studies conducted in the IGP region, also indicate that the implementation of these practices increases crop yields, farm income and input use efficiency[15–20].

While several studies have explored the potential of various climate-smart practices in improving crop productivity and farm income in experimental fields, there is limited information on their impacts on yield and income on real farm conditions of SLs. In addition, SLs can implement a range of CSA practices and technologies to minimize the adverse effects of climate change and variability, but their adoption decisions are largely dependent on economic benefits associated with the interventions. IGP is already subjected to periodic extreme weather events, such as, increased temperature, floods as well as droughts leaving significant portions of cropland uncultivated thus affecting the crop yield. It is expected that implementation of CSA practices and technologies could improve crop yields, bring abandoned land under cultivation and increase the income of smallholder farmers.

In this study, we explored the potential economic benefits of selected CSA practices to smallholder farmers in the IGP of India, by providing evidences of how CSA practices improve crop yields and farm income, compared to their respective conventional counterparts. Farmers are adapting to climate change/variability by adjusting crop rotations, using new crop varieties, changing planting dates and timings, and bringing necessary changes in other variable inputs such as tillage, nutrients and irrigation water. The net benefits of adaptation to climate change are estimated, based on net reduction in climate change damages due to specific adaptation actions[21]. But, such analysis requires time-series data or controlled experiments. Ex-ante estimation of economic benefits is an indirect method of estimating benefit of adapting agriculture to climate change/variability. This study provides valuable information to policymakers in development organizations and government working on designing strategies for climate change adaptation in agriculture and food security in the country.

Methods

Study sites

This study was conducted by the International Maize and Wheat Improvement Center (CIMMYT) in 2013, in the Climate-Smart Villages (CSVs). It was piloted by CGIAR research programme on Climate Change, Agriculture and Food Security (CCAFS) in the IGP of India (Figure 1). CSV is a model of local actions for climate risk management in farming communities that promote adaptation, build resilience to climate stresses, and enhance food security. Researchers, local organizations, farmers, and policymakers, collaborate to select the most appropriate technologies and institutional interventions based on global knowledge and local conditions to enhance productivity, increase income, achieve climate resilience and enable climate mitigation. The key focus of the CSV model is to enhance climate literacy of farmers and local stakeholders, and develop a climate resilient agricultural system by linking existing government village development schemes and investments. Promotion of combination of CSA practices and technologies is one of the major components in the CSVs. This approach is promoting a number of CSA practices revolving around seed, water, energy, nutrients and some risk averting instruments that help farmers in reducing climatic risks in agriculture[22]. These interventions are expected to increase crop yields and farmers' income in a sustainable way,

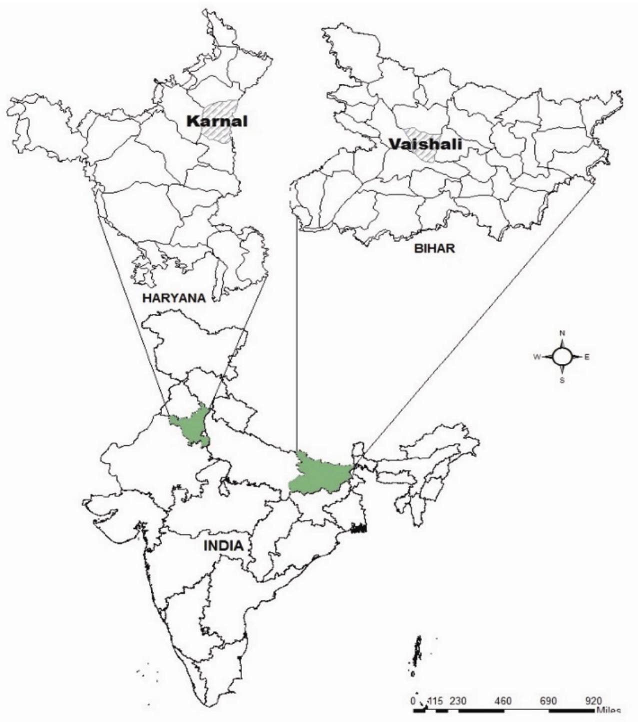

Figure 1. Study locations in Haryana and Bihar (Map source: Survey of India).

improve input-use efficiency and reduce GHGEs thus minimizing climatic risks in agricultural production systems.

The CSV model was started to pilot in 2011 in Haryana (Karnal) and Bihar (Vaishali), in India. These sites were selected due to their high agricultural vulnerability to climatic change and variability[23]. Sites considered for this study include highly flood and drought prone area in Bihar (i.e. CSVs in Vaishali district), and areas with rapidly declining groundwater table and increasing soil salinity, in Haryana (i.e. CSVs in Karnal district). In these areas, CCAFS and CIMMYT are implementing several climate-smart practices and technologies, in collaboration with local farmers to reduce the impact of climate change and variability in farming communities.

Rice–wheat is the dominant cropping system in both sites, but differ with regard to the level of agricultural development, farm size, and access to new technology and market. The mean annual rainfall in Karnal ranges from 600 to 700 mm, and in Vaishali 1100 to 1200 mm. Farmers in Karnal are relatively larger landholders than those in Vaishali districts. A large proportion of farmers in Vaishali districts are small landholders and of subsistence nature.

Data collection and analyses

A survey was conducted with 641 randomly selected households in Vaishali district (Bihar) and 626 households in Karnal district (Haryana). The complete survey of 1,267 households includes collection of information on households' socio-economic characteristics, crops and cropping practices, climate change risks in agriculture, and adaptation and mitigation strategies. Farmers in the study sites already have exposure to some CSA practices and technologies such as zero tillage, laser land levelling, crop residue management for soil and water conservation, improved crop varieties (flood and drought tolerant), and site-specific nutrient management practices[24]. During the survey a list of CSA practices and technologies was prepared and farmers were asked to check the ones implemented in rice and wheat crops, including detailed information on cost of implementation. Farmers were also asked to provide information on crop yields at the plot level before and after the implementation of such CSA practices and technologies.

An economic analysis of CSA interventions was conducted for selected practices and technologies. The practices and technologies implemented by less than 30 farmers were excluded to minimize the statistical errors. Based on the plot level input and output data before and after CSA interventions, we estimated cost of adoption, change in yields and net returns due to the implementation of particular CSA practice/technology in rice and wheat crops. Total increase in rice and wheat yields from the implementation of CSA practice/technology was converted to change in gross return multiplied by the respective market price. Net returns were calculated by deducting additional costs incurred for the implementation of CSA practice/technology. These additional costs for farmers to implement CSA practices and technologies were considered as the cost of adoption. Synergies among the CSA technologies was examined by comparing costs and benefits between single and combined technologies. A multiple regression was used to analyse the joint and individual effects of CSA practices and technologies including other socio-economic variables on change in cost of production and total yield in rice–wheat system.

Results and discussion

Adoption of CSA practices

Survey showed that many farmers in CSVs implement various CSA practices and technologies. Examples of CSA practices and technologies adopted by the farmers in the study areas include improved crop varieties for higher yield, varieties suitable to cope with drought, excess water or high temperature, laser land levelling, zero tillage, residue retention, site specific nutrient management, legume integration and cropping system diversification. About 60% of survey households in the study sites implement at least one CSA practice/technology in their farm. Majority of the CSA adopters prefer to use improved crop varieties (80%), laser land levelling (42%), crop rotations (23%) and zero tillage practice (11%). The improved crop varieties which are tolerant to severe floods, droughts and pest/diseases, use nutrients and water efficiently and can adjust to climate change and variability[24,25]. These varieties can be sown in different planting dates in a cropping season to adjust with changing monsoon time and temperatures. Laser land levelling and zero tillage could be water saving technologies for water deficient areas. For example, laser land levelling, by making the field well levelled, enhances water use efficiency compared to unlevelled fileds[20,26,27]. Similarly, zero tillage with residue retention conserves soil moisture, reducing evaporative loss of moisture thus requiring less water than conventionally tilled fields[19].

Crop diversification ensures differential nutrient uptake and use between two crops. For instance, inclusion of nitrogen fixing crops such as groundnuts, beans, and cowpeas will enhance soil fertility and nutrient supply to subsequent crops[28]. Crop diversification over time can be considered as a safety net on farmers' income if one crop is severely affected by the climate extremes. Other CSA practices such as residue management, direct seeded rice (DSR) and Site-Specific Nutrient Management (SSNM) are not quite popular among farmers. Only less than 10% survey households are implementing them. However, many studies indicate that the retention of crop residues, DSR and SSNM enhance nutrient and water use efficiencies leading to increased crop yields and economic benefits[16,17,19]. During the survey, we found that farmers do not retain crop residue in the field primarily because they value it as an important source of livestock feed. Farmers are reluctant to use DSR because of weed management problem during rice season. Farmers perceive puddling (wet tillage) and keeping standing water in the rice field as an important strategy for weed management. However, rice varieties suitable for DSR and herbicide molecules for effective weed management under DSR are evolving over time, which need to be disseminated among farming communities for wide scale adoption of DSR. Similarly, many farmers are not aware of the benefit of SSNM. Government extension agents, the primary source of information for farmers, are also less aware of tools, techniques and decision support systems available for implementation of SSNM in smallholder production systems.

Economic benefits of CSA adoption

This study estimated the impact of selected CSA practices and technologies adoption on crop yields, cost of inputs and net returns. Survey results indicate that a majority of the farmers have achieved greater yields in rice and wheat crops after the implementation of CSA practices. Use of improved seeds, zero tillage and laser land levelling increased total production in rice–wheat system by 19%, 6% and 10% respectively (Table 1). Use of improved seeds has substantially increased the yields (by 1.03 tonne ha^{-1}) and net return (by INR 15,712 ha^{-1}). Results also indicate that laser land levelling increases yield by 10% in rice–wheat system with change in yield by 0.33 tonne ha^{-1}. The average net return from the use of laser land levelling was INR 8,119 ha^{-1} yr^{-1}. These results are very close to previous studies. For instance, one research indicated that the yield increased by 6.7–8.8% and farmer benefited additional INR 8,061 ha^{-1} yr^{-1} in Haryana and Punjab by adopting laser land levelling in the rice–wheat system[26]. Agricultural land levelling increases water and nutrient use efficiency, improves crop establishment and weed control in the crop field, that lead to higher yields than in unlevelled fields[27,28].

Farmers also achieve some improvement in crop yields (6%) and substantial reduction in input costs by 41% under the zero tillage practice. The adoption of zero tillage in rice–wheat system provides additional return of INR 6,951 ha^{-1}. Several field experiments conducted in the IGP of India also indicate that the adoption of zero tillage improves crop yields and reduces cost of production as compared to conventional tillage[16,17,19,29]. Our result shows that a combination of improved seeds with zero tillage and laser land levelling technologies can improve crop yields as well as net returns. The yields and net returns are higher in plots with improved seeds and laser land leveling combined (0.87 tonne ha^{-1} and INR 14,194 ha^{-1}) and improved seeds and zero tillage combined (0.94 tonne ha^{-1} and INR 15,303 ha^{-1}) than in plots with laser land levelling (0.33 tonne ha^{-1} and INR 8,119 ha^{-1})

Table 1. Impacts of climate-smart agricultural technologies on production, cost and income in rice–wheat system

CSA intervention	% change in total production	% change in total input cost	Change in yield (t/ha)	Change in input cost (INR ha)	Net return (INR ha)
Improved seeds (IS)	19	52	1.03	1,402	15,712
Laser land levelling (LLL)	10	9.5	0.33	3,037	8,119
Zero tillage (ZT)	6	–41	0.36	–1,577	6,951
IS + LLL	17	63	0.87	1,752	14,194
IS + ZT	16	6	0.94	234	15,303

Zero tillage has substantially reduced total input cost due to reduction in land preparation costs.

Table 2. Factors affecting change in variable cost of production and total production

Variable	Change in total input costs (INR)	Change in total production (qt)
Improved seeds (dummy)	3068.023 (2515.30)	27.054** (9.32)
Laser levelling (dummy)	4297.202*** (686.49)	6.948** (2.54)
Zero tillage (dummy)	–425.968 (923.56)	14.898*** (3.42)
Credit (dummy)	1804.975* (704.54)	13.373*** (2.61)
Land size (ha)	650.720*** (73.19)	2.504*** (0.27)
Agri. income	0.021*** (0.01)	0.000 (0.00)
Constant	–2484.872 (2532.79)	–18.793* (9.39)
R^2	0.263	0.283
N	613	613

$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Value in parenthesis indicates standard error.

or zero tillage (0.36 tonne ha^{-1} and INR 6,951 ha^{-1}) alone. These results indicate some level of synergy among the CSA practices in the study areas.

Effects of CSA practices on total cost and production

We examined effects of several variables on change in total input costs and total crop production in the rice–wheat system. Many socio-economic variables such as family size, age of household head, education, gender and years of farming experience were not significant, thus excluded from econometric analysis. Table 2 presents effect of CSA practices adoption and other economic variable on change in total input costs and total crop yield. Results indicate that adoption of improved seeds does not significantly change total input costs, however significantly changes the total yield ($p < 0.05$, Table 2). This result implies that farmers can achieve higher yield by adopting improved seeds without significant cost implication.

Laser land levelling significantly influences the change in total input costs, whereas zero tillage has no significant effects on change in total input costs. Both CSA technologies significantly affected the change in total yield in rice–wheat system. Farmers with access to local credit services may invest on CSA technologies such as purchasing improved seeds, laser land levelling and zero tillage machines. Results also indicate that access to credit services, large land holding size and total agricultural income, would have positive effects on the change in total input costs and total production in the rice–wheat system.

Conclusions

The adaptation of rice–wheat system to climate change and variability requires implementation of various CSA practices and technologies that can improve the efficiency of resource use and productivity, and minimize the negative impacts of climate change and variability. This study assessed the adoption of CSA practices and technologies and economic benefits of most preferred CSA practices for small farmers in the IGP of India. Results indicate that a large number of farmers are adopting various climate-smart practices and technologies in CSV pilot areas. The adoption of these practices provides substantial economic benefits to smallholder farmers. The assessment indicate that CSA practices help small farmers in the IGP of India to achieve higher productivity and income, than they would have without these practices. Thus, scaling out of such CSA practices and technologies in other locations of the IGP region would benefit a large number of farmers and potentially reduce the negative impacts of climate change and variability on rice–wheat cropping system in the IGP.

A number of factors may affect adoption of CSA practices and technologies by small farmers. Despite economic benefits, many variables such as farmers' access to credits, landholding size and agricultural income may significantly influence farmers' decision to implement CSA practices and technologies in their farm. Farmers normally hesitate to invest into risky activities even though there is potential for substantial economic benefits. Thus, policies that minimize farmers' financial burden to adopt CSA technologies should be designed and implemented for scaling out in the IGP and beyond.

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