



# Performance of portfolios of climate smart agriculture practices in a rice-wheat system of western Indo-Gangetic plains

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## ABSTRACT

Several resource use efficient technologies and practices have been developed and deployed to address the challenges related to natural resource degradation and climatic risks management in rice-wheat (RW) rotation of Indo-Gangetic Plains (IGP). However, the practices applied in isolation may not be effective as much as in combination due to changing input responses under varied weather abnormalities. Therefore, a multi-location farmer's participatory strategic research was conducted to evaluate the effects of layering key technologies, practices and services in varied combinations and compared with business as usual (farmer's practice) for productivity (crop, water and energy), profitability and global warming potential (GWP) in a RW system. Altogether, six scenarios were compared that includes; Farmer's practice (FP); Improved FP (IFP) with low intensity of adaptive measures; IFP with high intensity of adaptive measures (IFP-AM); Climate smart agriculture (CSA) with low intensity of adaptive measures (CSA-L); CSA with medium intensity of adaptive measures (CSA-M); CSA with high intensity of adaptive measures (CSA-H). Results revealed that climate smart agricultural practice with high intensity of adaptive measures (CSA-H) recorded 7–9 and 19–26% higher system productivity and profitability, respectively compared to farmers' practice in all the three years. CSAPs (mean of CSA-L, CSA-M and CSA-H) improved the system productivity and profitability by 6 and 19% (3 yrs' mean) whereas, IFPs (mean of IFP and IFP-AM) by 2 and 5%, respectively compared to farmer's practice (11.79 t ha<sup>-1</sup> and USD 1833 ha<sup>-1</sup>). CSA with high (CSA-H) and medium (CSA-M) intensity of adaptive measures saved 17–30% of irrigation water and improved irrigation and total water productivity (WP<sub>i</sub> and WP<sub>i+R</sub>) by 29–54 and 21–38%, respectively compared to FP in the study years. Across the years, CSA-H improved the energy-use-efficiency (EUE) and energy productivity (EP) by 43–61 and 44–56% respectively, compared to farmers' practice. On 3 years mean basis, CSA-H lowered global warming potential (GWP) and greenhouse gas intensity by 40 and 44% respectively, compared to FP (7653 kg CO<sub>2</sub> eq ha<sup>-1</sup> yr<sup>-1</sup> and 0.64 kg kg<sup>-1</sup> CO<sub>2</sub> eq ha<sup>-1</sup> yr<sup>-1</sup>). On 3 years mean basis, our study revealed that CSA with high intensity of adaptive measures (CSA-H) increased 8% in system productivity, 23% in profitability, 31% in total water productivity and 53% in energy productivity with 24% less water while reducing the GWP by 40%. The improvement in yield, income as well as use efficiency of water and energy and reduction in GHGs was increasing with layering of portfolio of practices on farmers' practice. This study helps in prioritizing the technological practices from the portfolio of CSAPs for maximizing crop productivity, profitability and input use efficiency while improving the adaptive capacity and reducing the environmental footprints.

## 1. Introduction

In South Asia, home to about 1.5 billion people, slowdown in the growth rate of cereal production and increasing population pressure

have emerged as formidable challenges for the future food and nutritional security. These challenges will be more intense under emerging scenarios of natural resource degradation, energy crisis, volatile markets and risks associated with global climate change (Jat et al., 2016;

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Lal, 2016). During 1965–2015, in process of achieving multi-fold increase in crop production in the region, inefficient use and inappropriate management of non-climate production resources (water, energy, agro-chemicals) have vastly impacted the quality of the natural resources and also increased vulnerability to climatic variability affecting farming adversely. The natural resources in South Asia especially in Indo-Gangetic plains (IGP) are 3–5 times more stressed due to population, economic and political pressures compared to rest of the world (Jat, 2017). This can potentially add to climatic risks, and making a large number of people more vulnerable to climatic hazards in the region. Further, in south Asia during last one decade, the growth rate of the agriculture production is not significantly increased with the population which leads to more risk. With no scope for horizontal expansion of farming, the future food demand of growing population has to be met mainly through increasing yield per unit area with lesser external inputs (labor, water and energy) while protecting the environment. Achieving all these under more variable and uncertain climatic condition at present and future is the foremost challenges of present time all across the IGP (Lal, 2013; Jat et al., 2016; Campbell et al., 2016). Having high risks of climate change induced extreme weather events, the crop yields in the region are predicted to decrease from 10 to 40% by 2050 with risks of crop failure in several highly vulnerable areas (Jat, 2017). Increase variability in both temperature and rainfall patterns, changes in water availability, shift in growing season, rising frequency of extreme events such as terminal heat, floods, storms, droughts, sea level rise, salinization and perturbations in ecosystems have already affected the livelihood of millions of people.

Rice-wheat (RW) is the most important cropping system for food security in South Asia (13.5 Mha), providing food for more than 400 million people (Ladha et al., 2003). The concerns of natural resource degradation and increased intensity of risks associated with weather variability in the intensively cultivated IGP, the food bowl of South Asia, are multiplying. The area under the RW system covers ~32 and 42% of total rice and wheat area, respectively (Saharawat et al., 2012) and is almost static and the productivity and sustainability of the system are threatened because of the inefficiency of current production practices, shortage of resources such as water and labour, open field burning of crop residues and socioeconomic changes (Ladha et al., 2003; Chauhan et al., 2012; Lohan et al., 2018). Further, climate change on the one hand, and changing land use pattern, natural resource degradation (especially land and water), urbanization and increasing pollution on the other hand could affect the ecosystem in this region directly and also indirectly through their impacts on climatic variables (Lal, 2016). For example, about 51% of the IGP may become unsuitable for wheat crop, a major food security crop for India, due to increased heat-stress by 2050 (Lobell et al., 2012; Ortiz et al., 2008). Similarly, water table in north western IGP being depleted at  $13\text{--}17\text{ km}^3\text{ yr}^{-1}$  (Rodell et al., 2009) due to over-pumping for rice will have serious impacts on rice production. Therefore, adaptation to climate change is no longer an option, but a compulsion to minimize the loss due to adverse impacts of climate change and reduce vulnerability (IPCC, 2014). Moreover, while maintaining a steady pace of development, the region would also need to reduce its environmental footprint from agriculture. Management practices that provide opportunities to reduce GHGs emission and increasing carbon sequestration is required for resilience in production systems (Sapkota et al., 2014b). Considering these multiple challenges, agricultural technologies that promote sustainable intensification and adapting to emerging climatic variability yet mitigating GHG emissions are scientific research and development priorities in the region (Dinesh et al., 2015). Climate smart agriculture practices (CSAPs) related to water (e.g. direct seeded rice, laser land leveling, alternate wetting and drying and weather forecast based irrigation), nutrient (e.g. SSNM through nutrient expert tools, green seeker, slow release nitrogen fertilizer), carbon (e.g. residue retention and incorporation), weather (index based crop insurance), energy (e.g. laser land leveling, direct seeded rice, zero tillage) and

information and knowledge (e.g. ICTs) have been developed and validated (Ajani, 2014; Amin et al., 2016; FAO, 2010; Jat et al., 2016). However, these CSAPs in isolation may or may not play their potential role in adapting to climate risks and mitigating GHG emissions in RW production system. Therefore, layering of these practices and services in optimal combinations may help in adapting to climate risks and building resilience to extreme weather and climate variability, under diverse production systems and ecologies to ensure future food security.

To the best of our knowledge, there is no systematic research evidence available on layering of different management practices (CSAPs) on productivity, profitability, resource use efficiency under favorable as well as unfavorable climate risk scenarios in most of the production systems. Rice-wheat system of IGP being important for food security and challenged by projected climate change consequences, we conducted participatory strategic research trials to evaluate the portfolios of agriculture practices (CSAPs) under six scenarios to understand what combination of practices (portfolio of practices) are more important in terms of maximizing crop productivity and profitability, water and energy use efficiency while reducing the greenhouse gases (GHGs).

## 2. Material and methods

### 2.1. Experimental site and weather condition

Participatory strategic research trial was conducted during for three years (2014–15 to 2016–17) at farmers' fields in three different climates smart villages (CSVs; <https://ccafs.cgiar.org/publications/climate-smart-villages-haryana-india#.WO3-5OQ6yUk>) of the Indian Haryana state in the Northwest IGP: Birnarayana (29°75' N, 76°86' E), Anjanthali (29°83' N, 76°88' E) and Chandsamand (29°80' N, 77°10' E) in Karnal district of Haryana, India. The research sites are typically rice-wheat system dominated and has semi-arid tropical climate, characterized by hot and dry summer (April–September) and cold winters (October–March). The average annual rainfall of the area is 700 mm, of which 80 per cent occurs during the month of June to September. The mean annual maximum and minimum temperature is 34 and 18 °C, respectively and relative humidity remains 60–90% throughout the year. Seasonal weather data of study period and long term average data are presented in Fig. 1.

### 2.2. Soil sampling and analysis

Before starting the experiment, baseline soil samples were collected from 0 to 5, 5 to 15 and 15 to 30 cm soil depths using an auger of 5-cm internal diameter. For soil sampling, each plot was divided into four grids. Within each grid cell, soil was collected from four spots and composited for each depth. Bulk Density (BD) was measured using pistons auger (Chopra and Kanwar, 1991) and textural class was determined by the United States Department of Agriculture (USDA) system. Soil pH and electrical conductivity (EC) was determined in the saturation extract of 1: 2 (soil: water suspension) solution as described by Richards (1954). Soil organic carbon was analysed using Walkley and Black's (1934) rapid titration method. The available N in soil was determined by alkaline permanganate method (Subbiah and Asija, 1956), available P in 0.5 M NaHCO<sub>3</sub> extracts by Olsen et al. (1954) method and exchangeable K in IM NH<sub>4</sub>OAc-extracts by flame photometer method (Jackson, 1973). The experimental soil was silty loam in texture and low in nitrogen and medium in available phosphorus and potassium. The initial soil characteristics of the experimental sites are given in Table 1.

### 2.3. Experimental details and scenarios description

The experiment was started in the summer season 2014 with six treatments combinations layered with different management protocols/interventions over farmer practice. These scenarios consisted of 9

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