Indian Journal of Agricultural Sciences **88** (10): 1543–51, October 2018/Article

Impact of climate-smart agricultural practices on growth and crop yields of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system in north-western Indo-Gangetic Plains

S K KAKRALIYA[1], ISHWAR SINGH[2], R S DADARWAL[3], L K SINGH[4], R D JAT[5], H S JAT[6] and M L JAT[7]

Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125 001

Received: 09 June 2018; Accepted: 11 July 2018

ABSTRACT

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) production systems are the major contributor to national food security, which became unsustainable with passing of time due to inappropriate management and use of natural resources, inputs and technologies and is further aggravate with climate change induced risks. And if the business as usual in production approaches may not be able to cope up with the projected climate changes effects. Therefore, a multi-location farmer's participatory strategic research was conducted to evaluate the effects of layering of key technologies, practices and services in varied combinations and compared with business as usual (farmer's practice) for sustainability of rice and wheat productivity. In our present study, six scenarios: 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) were compared. The results revealed that CSAPs (CSA-L, CSA-M, and CSA-H) recorded higher plant height, panicles per sq m and biomass accumulation but lesser grains per panicle and 1000-grain weight compared to FP (transplanted rice; TPR). Rice yield was not much influenced under different management scenarios. The unfilled grains per panicle under IFP-AM, CSA-L, CSA-M, and CSA-H were 17, 18, 15 and 14% higher compared to FP. Growth and yield parameters of wheat were recorded higher under CSAPs during all the years. Three years mean, CSA-H, CSA-M and CSA-L recorded 16,14 and 11% higher grain yield compared to that of FP (5.06 q/ha), respectively. Improved farmer's practices (mean of IFP and IFP-AM) recorded 4% higher yield over FP in all the years. Intensive tillage-based scenarios (FP) showed water stagnation for long period (6 days) due to untimely rainfall (on 2 March 2015 with the amount 98.8 mm) which ultimately turned into lower grain yield but such factors did not influence grain yield under CSAPs. Therefore, our study results suggest that CSA practices should be promoted in dominated RW production region for increasing productivity and climate change mitigation.

Key words: Best management practices, Climatic variability, Conservation tillage, Growth, Yields

Rice-wheat (RW) is the most important cropping system for food security in South Asia, providing food for more than 400 million people (Ladha *et al.* 2003). In India, the system contributes 26% of total cereal production and 60% of total calorie intake (Gupta *et al.* 2003) and contributes about 40% of the country's total food basket (Gupta and Seth 2007). The area under the RW system covers around 32% and 42% of total rice and wheat area, respectively (Saharawat *et al*. 2012). The productivity and sustainability of the system are threatened because of the inefficiency of current production practices, shortage of resources and socio-economic changes (Ladha *et al.* 2003, Chauhan *et al.* 2012). Pressure is increasing on the limited land, water, and environmental resources for producing more food to match the demand of the burgeoning population.

The conventional farmers' practices of transplanting rice seedlings manually after repeated dry and wet tillage (Puddling) followed by conventionally tilled wheat seed broadcasting contributes significantly to the challenges like, declining soil fertility (Jat *et al*. 2014), depletion of

[1]Ph D Scholar (e mail: kakraliyask@gmail.com), [2]Professor (e mail: ishwarsingh718@gmail.com), [3]Assistant Scientist (e mail: dadarwal007@yahoo.co.in), Division of Agronomy, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar. [4]Research Associate (e mail: l.singh@cgiar.org), Borlaug Institute for South Asia (BISA), CIMMYT, Ludhiana, Punjab. [5]Scientist (e mial: sundahau04@gmail.com), Division of Agronomy, Chaudhary Charan Singh Haryana Agricultural University. [6]Senior Agronomist (e mail: h.jat@cgiar.org), [7]Senior Agronomist (e mail: m.jat@cgiar.org), International Maize and Wheat Improvement Centre (CIMMYT)- NASC Complex, New Delhi.

ground water, increasing shortage of labor and energy, rising problem of salinity and alkalinity (Bhattacharyya *et al.* 2015), multiple micronutrient deficiency, emergence of herbicide resistant and shift of weed flora besides environmental pollution through emission of greenhouse gases (GHGs) and large scale burning of rice straw are very complex and serious issues in RW belt of IGP (Hobbs *et al*. 2008,Timsina and Connor 2001). Intensive puddling in rice increase in soil strength in surface and sub-surface layers due to illuviation of clay, iron and manganese compounds; decrease in hydraulic conductivity and infiltration leads to water stagnation, poor root development, and low recharge of aquifers (Gathala *et al.* 2011, Bhushan and Sharma 1999). Economically, RW cropping system is becoming less and less profitable because of increasing input costs involved with conventional tillage (CT) practices (Gathala *et al.* 2014). High temperature during wheat maturity suppress the current photosynthesis, inhibits starch synthesis, shortens grain filling duration and rate of grain filling (Lobell *et al.* 2012) and all leading to shrivelled grain, poor grain quality and lower yields. Pathak *et al.* (2003) reported a yield loss of 15-60 kg/ha/day if wheat planting is delayed beyond mid-November in NW India.

Nonetheless, 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. Moreover, climate change, on the one hand, can intensify the degradation process of natural resources which are central to meet the increased food demand, while on the other hand; changing land use pattern, natural resource degradation, urbanization and increasing pollution could affect the ecosystem in this region directly and also indirectly through their impacts on climatic variables (Lal 2016, Jat *et al.* 2016). For example, about 51% of the Indo-Gangetic Plains 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). 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. Considering these multiple challenges, agricultural technologies that promote sustainable intensification and adapting to emerging climatic variability yet mitigating GHG emissions (climate-smart agricultural practices) are scientific research and development priorities in the region (Dinesh *et al.* 2015).

Climate-smart agriculture, a set of smart management practices, viz direct seeded rice, precision land levelling (PLL), tensiometer, and weather forecast based irrigation, site specific nutrient management through nutrient expert tools, green seeker, slow release nitrogen fertilizer, right placement of fertilizers, residue retention/incorporation, index based crop insurance, weather forecast, zero tillage and Information and communication technology (ICT); are such innovative approaches that have demonstrated as the potential strategies to enhance farm productivity, making crop production resilient to changing climate and to reduce ecological footprint of agricultural production system for sustainable food security.

To the best of our knowledge, there is no systematic research evidence available on the layering of different management practices on crop growth attributes, yield parameters and yields under favorable as well as unfavorable climate risk scenarios in most of the production systems. RW 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 growth attributes, yield parameters, and yields.

MATERIALS AND METHODS

Field experiment was carried out during *kharif* and *rabi* seasons of 2014-15 to 2016-17 with RW system at farmers' fields in three different climate smart villages (CSVs; https://ccafs.cgiar.org/publications/climate-smart-villages-haryana-india#.WO3-5OQ6yUk) at Birnarayana (29 º75ʹN, 76 º 86ʹE), Anjanthali (29 º83ʹN, 76 º 88ʹE) and Chandsamand (29 º80ʹN, 77 º 10ʹE) of Karnal, Haryana, India. These three research trails were under continuous rice-wheat rotation for several years and also before the establishment of the experimental trials. The climate of Karnal region is sub-tropical characterized by hot and dry summer and cold winters. The area receives about 700 mm annual rainfall, 80% of which occurs during the months of June to September. The soil of the experimental field was silt loam in texture, with pH; 8±0.12, electrical conductivity (Ec); 0.49±0.05 dS/m (1:2: soil: water), Walkley-Black organic carbon (OC); 0.66±0.087%, $KMnO_4$ oxidizable N; 185±12.3 kg/ha, 0.5 M $NaHCO_3$ extractable P; 26.2±3.2 ha, and 1N NH_4OAc extractable K; 314±34.8 kg/ha. Soil bulk density at the start of the experiment was 1.54±0.03 Mg/m. The treatment initiated in different scenarios as research protocol (Table 1).

The field experiment was started in the *kharif* season 2014, with six treatments referred to as scenario (s). Six scenarios with the layering of various management practices are Farmers' practice (FP), Improved FP with low Intensity of adaptive measure (IFP), Improved FP with high intensity of adaptive measure (IFP-AM), CSA with low-intensity of adaptive measure (CSA-L), CSA with medium intensity (CSA-M) and CSA with high intensity of adaptive measure (CSA-H). These scenarios basically consisted of 9 interventions, i.e. tillage and crop establishment, precision land-leveling (PLL), cultivars, crop residue management, water management, nutrient management, information, and communication technology (ICT) and index-based crop insurance. Each scenario was evaluated in production scale plots (about 1500-2000 m^2) and repeated in three locations.

Table 1 Scenario notations and description of management protocols under different scenarios in rice-wheat (RW) rotation

Scenarios		Tillage	Crop establishment	Laser land leveling	Cultivars	Residue management	Water management	Nutrient management	ICT	Crop insurance
Name	Details									
FP	Business as usual (FP)	CT	TPR with random geometry. CTW using seed broadcasting	No	Pusa 44; PBW 343	FP, Residue removed	FP	FFP	None	None
IFP	FP with low intensity of adaptive measures (IFP)	CT	TPR with random geometry. CTW using seed broadcasting	No	Pusa 44; PBW 343	100% of rice and 25% of wheat residue incorporated	FP	FFP	None	None
IFP-AM	IFP with high intensity of adaptive measures (IFP-AM)	RT	DSR sown with MCP. RTW sown with RDD	No	Pusa 44; HD 2967	Same as in IFP	SR	RDF	None	None
CSA-L	CSA with low intensity of adaptive measures (CSA-L)	RT-ZT	DSR sown with MCP. ZTW sown with HS	Yes	PR 114; HD 2967	100% rice residue retained and 25% wheat residue incorporated	SR	RDF	None	None
CSA-M	CSA with medium intensity of adaptive measures (CSA-M)	ZT	DSR and ZTW sown with HS	Yes	PR 114; HD 2967	100% of rice residue and 25% of wheat retained	Tensiometer based	RDF + GS guided N	Yes	Yes
CSA-H	CSA with high intensity of adaptive measures (CSA-H)	ZT	Same as in CSA-M	Yes	PR 114; HD 2967	Same as in CSA-M	Tensiometer based	NE + GS guided N	Yes	Yes

FP- Farmer's practice; IFP- improved farmer's practice; CSA- climate smart agriculture; CT- conventional tillage; RT- reduced till; ZT- zero till; TPR- transplanted rice; CTW- conventional till wheat; DSR- direct seeded rice; MCP-multi crop planter; RTW- reduced till wheat; RDD-rotary disc drill; ZTW- zero till wheat; HS-happy seeder; SR- State recommendation for irrigation; FFP- farmer's fertilizer practice; RDF- recommended dose of fertilizer; NCU- neem coated urea; GS- green seeker; NE- Nutrient expert based fertilizer recommendation; ICT- information and communication technology.

Before the start of the experiment, about 60 random farmer's families were surveyed from nearby villages to find out the portfolios of their current practices in RW rotation. Manual transplanting of rice in puddled fields is commonly practiced in this region. About 30-35 days old rice seedling was used for transplanting into puddled field in a random pattern (2 seedlings/hill). Wheat was sown at the end of November to the first week of December depending on the type (coarse rice/ basmati rice) and duration (short day/long day) of rice grown. The optimum time for wheat sowing is the first half of the November month. Wheat was sown by manual broadcasting of seeds after conventional (intensive) tillage practices (Table 2). Although the recommended dose of nitrogen, phosphorus and potash (NPK) for both rice and wheat crop is 150:60:60 kg/ha, but farmers in this region apply excess N, optimum P and no K (Table 3). Residue burning is still a widely prevalent practice among the farmers in the region, however, in our trial; rice residue was removed at ground level instead of burning to avoid the risk of unfortunate burning of residue-retained scenarios.

In this scenario, all the management practices were same as in FP except residue management. This scenario was planned to improve soil quality and reducing the GHG emissions by incorporating crop residues into the field instead of residue burning. Fertilizer application was given as per FP.

This scenario was designed to address the issues of labour, water, and energy which are becoming scarce and more expensive in present situation. In this scenario tillage operation was reduced by 33 and 40% in rice and wheat,

Table 2 Crop management practices for rice-wheat (RW) rotation under different scenarios

Scenarios/ Management practices	Scenario 1 (FP)	Scenario 2 (IFP)	Scenario 3 (IFP-AM)	Scenario 4 (CSA-L)	Scenario 5 (CSA-M)	Scenario 6 (CSA-H)
Field preparation	Rice- 2 pass of harrow, 1 pass of rotavator, 2 pass of puddle harrow followed by (fb) planking; Wheat- 2 pass of harrow and rotavator each fb planking	Same as in FP	Rice-1 pass of harrow, 1 pass of cultivator fb planking; Wheat- 1pass of harrow, 1 pass of cultivator fb planking	Rice- Same as in IFP-AM; Wheat- Zero tillage	Zero tillage	Same as in CSA-M
Seed rate (kg/ ha)[b]	12.5-100	Same as in FP	20 – 100	Same as in IFP-AM	Same as in IFP-AM	Same as in IFP-AM
Crop geometry	Random geometry	Same as in FP	22 cm – 20 cm	Same as in IFP-AM	Same as in IFP-AM	Same as in IFP-AM
Source of fertilizers	Urea (46:0:0) and Di-ammonium phosphate (DAP) (18:46:0)	Same as in FP	Urea, DAP, muriate of potash (MOP) (0:0:60), and NPK complex (12:32:16)	urea (46:0:0), DAP, MOP and NPK complex	Same as in CSA-L	Neem coated urea (46:0:0), DAP, MOP and NPK complex
Fertilizer (N:P:K)(kg/ ha)	Rice-195:58: 00; Wheat- 185:58:00	Same as in FP	Rice- 150:60:60; Wheat- 150:60:60	Same as in IFP-AM	Rice- 147:60:60 (in 1styr) 153:60:60 (in 2ndyr) and 158:60:60 (in 3rdyr); Wheat- 143:60:60 (in 1styr), 120:60:60 (in 2ndyr) and 134:60:60 (in 3rdyr)	Rice- 138:39:70 (in 1styr), 140:42:57 (in 2ndyr) and 145:44:57 (in 3rdyr); Wheat- 135:62:60 (in 1styr), 111:58:55 (in 2ndyr) and 122:56:55 (in 3rdyr)
Water management	Rice- Continuous flooding of 5-6 cm depth for 30-40 days after transplanting fb irrigation applied at alternate wetting and drying. Wheat- 4-6 irrigation as per requirement	Same as in FP	Rice- Soil was kept wet up to 20 days after sowing fb irrigation applied at hair-line cracks. Wheat- 4-6 irrigation as per critical crop growth stages	Same as in IFP-AM	Rice- Soil was kept wet till germination fb irrigation at -20 to -30 kPa matric potential; Wheat- Irrigation at -50 to -55 kPa matric potential	Same as in CSA-M

[a]Refer Table 1 for scenario description. [b]Seed treatment was done with Bavistin + Streptocycline @ 10+1 g per 10 kg seed-Raxil ® Tebuconazole 2DS (2% w/w) at 0.2 g a.i/kg seed

respectively compared to FP. Wheat was sown by rotary disc drill (RDD) under residue incorporation and rice by multi-crop planter (MCP) under residue incorporation conditions. The recommended dose of fertilizers (RDF) was 150:60:60 kg NPK/ha for each crop based on the recommendation of CCS Haryana Agricultural University, Hisar, India (Table 2). A foliar spray of iron sulphate ($FeSO_4$) @ 0.5% was done at 20 DAS in rice.

In this scenario, partial layering of CSA technologies over farmer's practices was done with the objective of addressing water, labour and energy crisis in RW production system. Before the start of the experiment, the area was levelled (zero gradient) using a laser-equipped drag scraper with an automatic hydraulic system powered by a 60-HP tractor. Wheat was sown using a Happy Seeder over full (100%) rice residue. All fertilizers but N was applied as in IFP-AM. N was applied through neem coated urea (NCU).

The main focus on this scenario was minimizing the effect of climatic variability (temporal as well as spatial) by the layering of component technologies. For nutrient management, RDF was given to both the crops as in IFP-AM except the third dose of nitrogen. Third N dose was given based on Green Seeker reading at 62 and 65 days after sowing in rice and wheat, respectively (Singh *et al*. 2011 and 2015). A foliar spray of iron sulphate ($FeSO_4$) @0.5% was done at 20 DAS in rice. Application of irrigation, herbicides, and insecticides were tailored based on short-term weather forecast (STWF) bulletin. Indian Farmers Fertiliser Cooperative (IFFCO) Kisan Sanchar Limited (IKSL) aired STWF through voice and text messages on registered farmer's cell number. Both the crops were insured with weather-based crop insurance during all the years. Weather Based Crop Insurance was done through Agriculture Insurance Company (AIC) of India Limited (http://www.aicofindia.com/) to mitigate the financial loss on account of anticipated crop yield losses from the incidence of adverse conditions of weather variability like excess rainfall, cold and heat stress. For this, 2 and 1.5% of total sum insured (62500 and 55000 `/ha for rice and wheat, respectively) were paid to AIC as a basic premium for rice and wheat, respectively. In all the seasons, crops were insured for abnormality but we did not face the weather abnormalities.

This scenario was designed for increasing productivity and profitability by adapting and building resilience to extreme weather and climate variability. In this scenario, all practices followed were same as CSA-M except nutrient management. Site-specific nutrient management (SSNM) approach was used to tailor the recommended nutrient doses using Nutrient Expert (NE) layered with Green Seeker guided N. Nutrient Expert® is an interactive, computer-based decision-support tool that enables implementation of SSNM in individual fields without soil test data (Pampolino et al., 2012 and Sapkota *et al*. 2014). The algorithm for calculating fertilizer requirements was developed from on-farm research data and validated over 5 years of testing. The software is currently available without charge for wheat, rice and maize systems in South Asia (http://software.ipni.net/article/nutrient-expert), confirmed on May 25, 2014.

Crop residue management, weed management and Irrigation management:These practices were done as per kakraliya *et al*. (2018).

Ten plants in each scenario were randomly selected and marked for recording of plant height of rice and wheat crops. In both the crops, at harvesting stage the numbers of effective tillers were counted from the 1 m^2 area randomly from four spots in each scenario, averaged and expressed as number of effective tillers/m^2 area. Panicles/spike length was measured in cm from 10 randomly selected tillers of tagged plants from each scenario at harvest. The length was measured from neck to the tip of the panicles/spike and average length was computed. The total number of filled grains for the 10 panicles/spike of randomly selected per plot was counted and their mean was worked out. From the representative samples of each scenario yield, the weight of 1000 grains (g) was recorded separately.

Crops were harvested manually from 8×5 m^2 randomly selected quadrate from three places within each plot for grain and straw yields. To express the overall impact of treatments on system productivity was calculated on rice equivalent yield (REY) basis for wheat grain yield. Grain yield of rice and wheat were recorded at 14% moisture content basis. System productivity (t/ha) was computed using Eq. (1).

REY (t/ha)= [{Wheat yield (t/ha)×MSP of Wheat (₹ t)}/ MSP of Rice (₹/t)] (1)

where, MSP is the Minimum support price.

The data recorded for different crop parameters were analysed using analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for randomized block design using SAS 9.1 software (SAS Institute, 2001). Where ANOVA was significant, the treatment means were compared using Tukey's honestly significant difference (HSD at 5% level of significance).

RESULTS AND DISCUSSION

Rice growth and yield parameters

Three year results of this study revealed that CSAPs (CSA-L, CSA-M and CSA-H) recorded higher plant height and panicles/m^2 with the lower, number of grains/panicle, 1000-grain weight and harvest index as compared to farmer`s practice (FP) (Table 3). Higher plant height may be due to greater competition for light with higher plant population in CSAPs as compared to FP. The results are in conformity with the findings of Choudhary *et al.* (2016) contrarily, more plant height was recorded with transplanted rice than DSR by Javaid *et al.* (2012). Higher panicle was due to more plants per unit area in CSAPs, which resulted into more number of effective tillers than farmers' practice (FP; TPR) (Table 3). The higher number of grains/panicle and 1000-grain weight in FP (TPR) might be attributed to comparatively lesser plant competition for water, nutrients and light due to availability of optimum space and an extended soil rhizosphere. These results are in consistent with findings of who also observed more grains/panicle and

Table 3 Effect of different management practices on growth parameters, yield attributes and yields of rice under different scenarios in 3 years (pooled of 3 yrs)

Scenarios[A]	Plant height (cm)	Tillers /m^2	Grains/panicle	Panicle length (cm)	1000-grain weight	Biomass (t/ha)	Grain yield (t/ha)
FP	98.7^{aB}	213^b	240^a	26.27^a	23.58^a	16.35^a	6.73^a
IFP	100.0^a	219^b	242^a	26.75^a	23.86^a	16.61^a	6.85^a
IFP-AM	96.9^a	355^a	15^b	24.28^c	22.14^c	16.74^a	6.64^a
CSA-L	97.7^a	354^a	153^b	24.32^{bc}	22.27^{bc}	16.91^a	6.65^a
CSA-M	98.1^a	360^a	157^b	24.65^{bc}	22.52^{bc}	16.97^a	6.73^a
CSA-H	100.3^a	368^a	163^b	25.09^b	22.71^b	17.32^a	6.90^a

[A]Refer table 1 for scenario description. [B]Means followed by a similar uppercase letters within a column are not significantly different at 0.05 level of probability using Tukey's HSD test.

test weight in TPR relative to DSR.

CSAPs produced a significantly higher number of effective tillers/m^2 in comparison to FP (Table 3). This was due to higher plant population per m^2 (Nawaz *et al.* 2017). The lower number of grains/panicle was recorded under CSAPs compared to FP. Probably, it was due to more competition for light and nutrients, a lower photosynthetic rate which resulted in reduced panicle length, a lesser number of grains/panicle and higher spikelet sterility under CSAP compared to FP. A higher number of grains/panicle under PTR as compared to DSR was reported by Akhgari and Kaviani (2011), and Choudhary *et al.* (2016).

During three year study, the higher number of sterile spikelets/unfilled grains/panicle was recorded under scenarios IFP-AM to CSA-H compared to FP (Fig 1). This was due to high plant density and unsuitable cultivation arrangement of the plant in CSAP (DSR) that might have caused compact canopy and decreasing the air circulation within the canopy. Full CSAP scenario (CSA-H) produced lesser chalky kernel per panicle as compared to IFPs and partial CSAP (CSA-L and CSA-M) (Fig 1). This could be due to the cumulative effect of high degree of layering management practices and appropriate use of all inputs during the growth period. Appropriate management practices might have increased grains per panicle by preventing the degeneration of spikelets when grain development takes place (Lalondeet *al.* 1997, Garrity *et al.*1986, Kumar 2016, Nawaz *et al.* 2017). Singh *et al*. (2015) ascribed that application of nitrogen with optical sensor at critical growth periods ensure the fulfilments of crop requirement for better crop growth.

Total biomass and grain yield

In this study, similar or higher biomass and yield trends under CSAPs as compared FP (Table 3). This might be due to synergetic effects of improved management practices (conservation tillage, smart crop establishment, PLL, suitable cultivars, precise water, and nutrient management and effective weed management etc.). Our results are in close conformity with the finding of (Kumar and Ladha 2011, Gathala *et al.* 2014, Nawaz *et al.* 2017). Higher grain yield (by 2.5%) under CSA-H relative to FP due to synergetic effect of layering of different management practices, viz residues retention maintain proper moisture level, SSNM practices facilitated balanced fertilization and better synchronization of nitrogen with plant needs that resulted into similar or higher yield (Singh *et al.* 2015, Jat *et al.* 2016) with greater nutrient use efficiency (Singh *et al.* 2015). But our results are in contrast to the lower yields of DSR found in some studies in the IGP region (Saharawat *et al*. 2010) because of they used isolation practices compared to a portfolio of management practices. The biomass was recorded higher under CSAPs compared to FP due to profuse tillering and higher plant growth (Nawaz *et al.* 2017). DSR has the advantage of early maturity of around 10 days than TPR allowing timely planting of succeeding wheat crop (Sidhu *et al.* 2007, 2015, Saharawat *et al*. 2010).

Wheat

Growth and yield parameters: Growth parameters, viz. plant height, tillers/m^2 of wheat recorded comparatively higher under CSAPs (mean of CSA-L, CSA-M, and CSA-H) than farmer`s practice (FP) during all the years of study (Table 4). This might be due to proper placement of the seed and fertilizer in the narrow slit made by a zero-seed drill, early emergence of wheat seedling and availability of higher soil moisture which helped the crop to perform better than the crop sown under farmer practice. These results are in

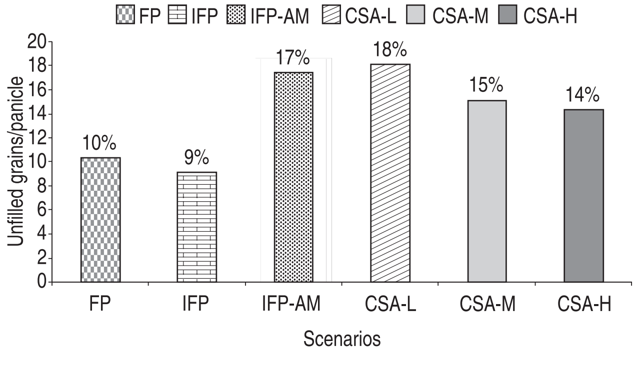

Fig 1 Layering of different management practices influences unfilled grains of a panicle of rice under different scenarios (pooled of 3 yrs).

Table 4 Effect of different management practices on growth parameters, yield attributes and yields of wheat under different scenarios in 3 years (pooled of 3 years)

Scenarios[A]	Plant height (cm)	Tillers/ m^2	Grains/ spike	Spike length (cm)	1000-grain weight	Biomass (t/ha)	Grain yield (t/ha)
FP	96.84^{dB}	368^{c}	47.43^{d}	10.1^{d}	41.19^{c}	11.45^{d}	5.06^{d}
IFP	98.4^{cd}	374^{c}	48.62^{d}	10.3^{d}	41.72^{bc}	11.66^{d}	5.15^{d}
IFP-AM	99.3^{bcd}	376^{c}	50.73^{c}	10.7^{c}	42.53^{ab}	12.16^{c}	5.39^{c}
CSA-L	100.5^{abc}	389^{b}	53.02^{b}	11.1^{b}	42.90^{ab}	12.71^{b}	5.64^{b}
CSA-M	101.6^{ab}	400^{a}	53.97^{ab}	11.5^{ab}	43.31^{a}	13.02^{a}	5.77^{ab}
CSA-H	103.0^{a}	403^{a}	54.80^{a}	11.5^{a}	43.42^{a}	13.14^{a}	5.85^{a}

Prefer Table 1 for scenario description. [B]Means followed by a similar uppercase letters within a column are not significantly different at 0.05 level of probability using Tukey's HSD test

agreement with the finding of Nawaz *et al*. (2017). Studies have shown that shallow hard pan caused by repeated wet tillage/puddling generally reduces root growth (Saharawat *et al*. 2010, Gathala *et al.* 2011) resulting in reduced tillering and ultimately lower grain yield.

Yield attributes of wheat also followed a similar trend as growth parameters. All the yield attributes, viz. spikes/ m^2, grains/spike and 1000-grains weight were significantly influenced by the layering of different management practices (Table 4). These attributes were higher under CSAPs as compared to farmer`s practice. The cumulative effect of CSAPs over the cropping cycles leads to improvement in yield attributes. The higher number of productive tillers were in line with higher number of total tillers and increase in 1000-grain weight could be due to increased accumulation of photosynthates in sink (grain) owing to it better growth and development and higher dry matter production with its translocation to reproductive plant parts (Kumar *et al.* 2013, Kakraliya *et al.* 2016). Spike length indicates the numbers of spikelets, which in turn affect the number of grains. Ear differentiation and development would depend on the availability of carbohydrates in the early stages of growth when there is competition with strong sinks like tillers, leaf, and stem. The sink capacity of grains is the product of a number of grains set and growth characteristics of individual grains (Reddy and Bhardwaj 1982). The increase in the length of spike also contributed to increasing in the number of grains/spike. Precision use of inputs might have increased grains per spike by preventing the degeneration of spikelets when grain development takes place (Reddy and Bhardwaj 1982).

Total biomass and grain yield: CSAPs increased the values of total biomass and yields of wheat than farmer`s practices (FP) and IFPs (mean of IFP and IFP-AM), which might be attributed to the better availability of soil moisture, moderated soil temperature and improved soil fertility due to a continuous supply of nutrients through mineralization of crop residues.

Wheat grain yield was influenced significantly with the layering of various crop management practices in all the years (Table 4). CSA-L, CSA-M, and CSA-H recorded 15.6, 14.0 and 11.5% (pooled of 3 yrs) higher yield compared to that of FP. Improved farmer's practices (mean of IFP and IFP-AM) and CSAPs recorded 6 and 14% (pooled of 3 years mean) higher yield respectively, over FP (Table 4). This might be due to improved management practices/technologies, precise land leveling, proper crop establishment, precise water management, effective and efficient weed and nutrient management. Better performance of zero tillage wheat with residue retention (Table 4) might be attributed to better soil physical conditions (Gathala *et al.* 2011) and high soil organic matter which might have helped in deeper root penetration and thus improving the uptake of water and nutrients. On the other hand, multiple tillage operations (conventional tillage wheat, CTW) degraded soil properties by increasing soil bulk density, soil compaction and lesser aggregation stability, which suppress the activities of beneficial microbes (Erenstein and Laxmi 2008) and thus subsequently affected the performance of wheat production (Saharawat *et al.* 2010, Gathala *et al.* 2011). Nutrient expert (NE) based management approach and Green Seeker guided N applications helped in higher yields and N-use efficiency over farmer's practices. Higher wheat productivity and N-use efficiency were recorded under precision nutrient management practices compared to conventional nutrient management practices (Sapkota *et al.* 2014, Singh *et al*. 2015). The biomass of wheat was significantly higher under CSAP followed by IFP-AM as compared to FP. These results are also in agreement with earlier researchers (Singh *et al.* 2011) who reported higher wheat yield with CA-based management practices. One of the important benefits of the happy seeder technology is that it provides an alternative to burning by managing rice residues and allows direct drilling of wheat in standing as well as loose residues (Sidhu *et al.* 2007, 2015).

System yield

RW system yield was found in the order of increasing trends with the intensity level of CSAPs or layering of CSAPs one over the others (Fig 2). Mean (pooled of 3 years) rice equivalents grain yield of RW system under CSA-H, CSA-M and CSA-H were increased by 8.2, 6.2 and 4.3%, respectively compared to farmers practice (Fig 2). Higher system grain yield with CSAPs might be due to improved management practices (Jat *et al.* 2011, Gathala *et al.* 2011). Similarly, our results are also in agreement with the work of

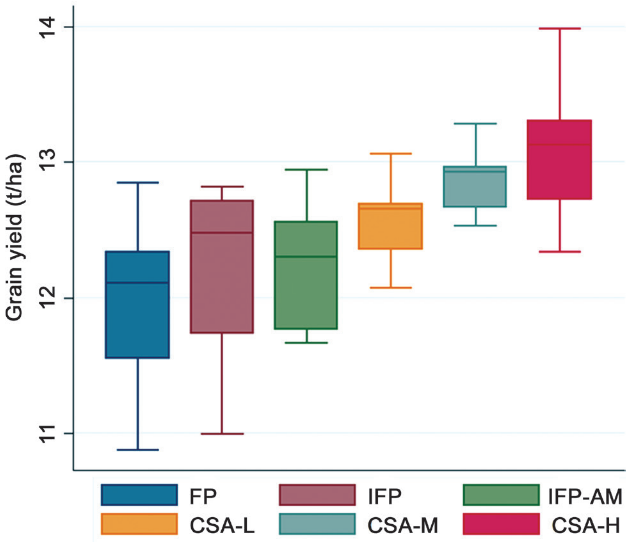

Fig 2 Layering of different management practices influences system grain yield different scenarios in 3 years (pooled data of 3 years).

Laik *et al.* (2014) who reported that the productivity of rice and wheat based cropping systems of South Asia increased substantially with an integrated approach.

Conclusion

Climate-smart agriculture is found to be an important vehicle to increase the productivity of RW system, increase food security, and reduce the climatic risk. Climate-smart agriculture practices (CSAPs) significantly influenced the growth parameters and yield attributes of rice and wheat, respectively. In our study, rice yield and biomass were not much influenced under different management scenarios. However, wheat yield was found in the order of increasing trends with the intensity level of CSAPs or layering of CSAPs over farmers practices (FP). Wheat yield under CSA based scenarios was 14% higher (mean of CSA scenarios over 3 years) compared to FP. RW system yield (rice equivalent) were increased (pooled 3 years) by 6.2% under CSAPs compared to FP. CSAP not only helps in maximizing crop productivity but also minimizes the adverse effects of associated climatic risks by improving adaptive capacity.

ACKNOWLEDGMENTS

The research was financed and supported from CGIAR Research Programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS) and Wheat Agri-Food Systems (WHEAT). We acknowledge the CGIAR Fund Council, Australia (ACIAR), Irish Aid, European Union, International Fund for Agricultural Development (IFAD), Netherlands, New Zealand, Switzerland, UK, USAID and Thailand for funding to the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). We also acknowledge the collaborations and support of Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar and ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal for this study. We also acknowledge the farmers Mr Harpreet Singh (village-Beernarayana), Mr Vinod Kumar (village-Anjanthali) and Mr Amit Rana (village-Chandsamand), Karnal for providing land and also participating in management activities and discussions during the research process. We also acknowledge the help of Munmun Rai and Kailash C Kalwaniya of CIMMYT.

REFERENCES

Akhgari H and Kaviani B. 2011.Assessment of direct seeded and transplanting methods of rice cultivars in the northern part of Iran. *African Journal of Agricultural Research* **6:** 6492–8.

Bhattacharyya R, Ghosh B, Mishra P, Mandal B, Rao C, Sarkar D, Das K, Anil K S, Lalitha M, Hati K M and Franzluebbers A J. 2015. Soil degradation in India: challenges and potential solutions. *Sustainability* **7**(4): 3528–70.

Bhushan L and Sharma P K. 1999. Effect of depth, bulk density and aeration status of root zone on productivity of wheat. *Journal of the Indian Society of Soil Science* **47**: 29–34.

Chauhan B S. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **26**: 1–13.

Choudhary K M. 2016. 'Diversification with sustainable intensification options for cereal systems of Western Indo-Gangetic plains through conservation agriculture and water management'. Ph D thesis, Department of Agronomy, CCS HAU, Hisar, India.

Dinesh D, Frid-Nielsen S, Norman J, Multamba M, Loboguearero Rodriguez A and Cambell B. 2015. Is climate smart agriculture effective? A review of selected cases CCAFS working paper No. 129.

Erenstein O and Laxmi V. 2008. Zero tillage impacts in India's rice-wheat systems: A review. *Soil and Tillage Research* **100**: 1–14.

Garrity D P, Oldeman L R and Morris R A. 1986.Rainfed lowland rice ecosystem: characterization and distribution. (*In*) *Progress in Rainfed Lowland Rice*, pp 3-23. International Rice Research Institute, Los Banos, Philippines.

Gathala M K, Kumar V, Sharma P C, Saharawat Y S, Jat H S, Singh M, Kumar A, Jat M L, Humphreys E, Sharma D K, Sharma S and Ladha J K. 2014. Optimizing intensive cereal based cropping systems addressing current and future drivers of agricultural change in the Northwestern Indo-Gangetic Plains of India. *Agriculture, Ecosystems and Environment* **187**: 33–46.

Gathala M K, Ladha J K, Saharawat Y S, Kumar V, Kumar V and Sharma P K. 2011. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. *Soil Science Society of America Journal* **75**: 1851–62.

Gupta R and Seth A. 2007.A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). *Crop Protection* **26**: 436–47.

Gupta R K, Hobbs P R, Jiaguo J, Ladha J K. 2003. Sustainability of post-green revolution agriculture. (*In*) *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, pp 1-25. J K Ladha *et al.* (Eds.), ASA Spec. Publ. 65, ASA, CSSA, and SSSA, Madison, WI.

Hobbs P, Sayre K. and Gupta R. 2008.The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society* **363**: 543–55.

IPCC. 2014. Summary for policymakers. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1–32.

Jat H S, Jat R K, Singh Y, Parihar C M, Jat S L, Tetarwal J P, Sidhu H S and Jat M L. 2016. Nitrogen management under conservation agriculture in cereal-based systems. *Indian Journal of Fertilisers* **12**: 76–91.

Jat M L and Aggarwal P K. 2014. Climate smart village in Haryana, India. CGIAR Research program on Climate Change, Agriculture and Food Security (CCAFS), CIMMYT. *http://wwww.cimmyt.org.* pp 1-12.

Jat M L, Dagar J C, Sapkota T B, Singh Y, Govaerts B, Ridaura S L, Saharawat Y S, Sharma R K, Tetarwal J P, Jat R K, Hobbs H and Stirling C. 2016a. Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. *Advances in Agronomy* **137**: 127–236.

Jat M L, Saharawat Y S and Gupta R. 2011. Conservation agriculture in cereal systems of south Asia: Nutrient management perspectives. *Karnataka Journal of Agricultural Sciences* **24**(1): 100–10.

Jat R K, Sapkota T B, Singh R G, Jat M L, Kumar M and Gupta R K. 2014. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research* **164**(1): 199–210.

Javaid T, Awan I U, Baloch M S, Shah I H, Nadim M A, Khan E A, Khakwani A A and Abuzar M R. 2012. Effect of planting methods on the growth and yield of coarse rice. *Journal of Animal* and *Plant Sciences* **22**(2): 358–62.

Kakraliya S K, Jat H S, Singh I, Sapkota T B, Singh L K, Sutaliya J M, Sharma P C, Jat R D, Ridaura S L and Jat M L. 2018. Performance of portfolios of climate smart agriculture practices in a rice-wheat system of western Indo-Gangetic plains. *Agricultural Water Management* **202**: 122–33.

Kakraliya S K, Yadav D D, Singh L K, Choudhary R, Choudhary K K, Kumar P, Kakraliya S S, Choudhary V, Prakash J, Dahiya S and Jat R D. 2016. Organic and inorganic fertilizers influence soil fertility, productivity and profitability of wheat (*Triticum aestivum* L.). *Ecology, Environment and Conservation* **22:** 137–43.

Kumar V and Ladha J K. 2011. Direct seeding of rice : recent developments and future research needs. *Advances in Agronomy* **111**(6): 299–360.

Kumar V, Jai S K, Singh Y, Kumar V, Jain S K and Singh Y. 2016. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal* **55**(4): 484–96.

Kumar V, Saharawat Y S, Gathala M K, Singh Jat A, Singh S K, Chaudhary N and Jat M L. 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-GangeticPlains. *Field Crops Research* **142**: 1–8.

Ladha J K, Dawe D, Pathak H, Padre A T, Yadav R L, Singh B and Hobbs P R. 2003. How extensive are yield declines in long-term rice-wheat experiments in Asia? *Field Crops Research* **81**: 159–180.

Laik R, Sharma S, Idris M, Singh A K, Singh S S, Bhatt B P, Saharawat Y, Humphreys E and Ladha J K. 2014. Integration of conservation agriculture with best management practices for improving system performance of the rice-wheat rotation in the Eastern Indo-Gangetic Plains of India. *Agriculture, Ecosystems and Environment* **195**: 68–82.

Lal R. 2016. Feeding 11 billion on 0.5 billion hectare of area under cereal crops. *Food and Energy Security* **5(4):** 239–51.

Lalonde S, Beebe D, and Saini H S. 1997. Early signs of disruption of wheat anther development associated with the induction of male sterility by meiotic-stage water deficit. *Sex Plant Reproduction* **10**: 40–8.

Lobell D B, Sibley A and Ortiz-Monasterio J I. 2012. Extreme heat effects on wheat senescence in India. *Nature Climate Change* **2:** 186–9.

Nawaz A, Farooqa M, Lal R, Rehman A and Rehman H. 2017. Comparison of conventional and conservation rice-wheat systems in Punjab, Pakistan. *Soil and Tillage Research* **169**: 35–43.

Ortiz R, Sayre K, Govaerts B, Gupta R, Subbarao G, Ban T,Hodson T, Dixon J, Ivanortizmonasterio J and Reynolds M. 2008. Climate change: Can wheat beat the heat? *Agriculture Ecosystems and Environment* **126**: 46–58.

Pampolino M, Majumdar K, Jat M L, Satyanarayana T, Kumar A, Shahi V B, Gupta N and Singh V. 2012. Development and evaluation of nutrient expert for wheat in South Asia. *Better Crops* **96**(3): 29–31.

Pathak H, Prasad S, Bhatia A, Singh S, Kumar S, Singh J and Jain M C. 2003. Methane emission from rice-wheat cropping system in the Indo-Gangetic plain in relation to irrigation, farmyard manure and dicyandiamide application. *Agriculture, Ecosystems and Environment* **97**: 309–16.

Reddy A S and Bhardwaj R B L. 1982. Water use studies in wheat as influenced by levels of nitrogen and phosphorus under limited and adequate irrigation. *Indian Journal of Agronomy* **27:** 22–7.

Saharawat Y S, Ladha J K, Pathak H, Gathala M, Chaudhary N and Jat, M L. 2012. Simulation of resource-conserving technologies on productivity, income and greenhouse gas GHG emission in rice-wheat system. *Journal of Soil Science and Environmental Management* **3**(1): 9–22.

Saharawat Y S, Singh B, Malik R K, Ladha J K, Gathala M, Jat M L and Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Research* **116**(3): 260–7.

Sapkota T B, Majumdar K, Jat M L, Kumara A, Bishnoi D K, McDonaldd A J and Pampolino M. 2014. Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research* **155**: 233–44.

Sidhu H S, Singh M, Humphreys E, Singh Y, Singh B, Dhillon S S, Blackwel J, Bector V, Singh M and Singh S. 2007. The Happy seeder enables direct drilling of wheat into rice stubble. *Australian Journal of Experimental Agriculture* **47**: 844–54.

Sidhu H S, Singh M, Singh Y, Blackwell J,Lohan S K, Humphreys E, Jat M L, Singh Vand Singh S. 2015. Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. *Field Crops Research* **184**: 201–12.

Singh B, Singh V, Purba J, Sharma, R K, Jat M L, Singh Y and Gupta R. 2015. Site-specific fertilizer nitrogen management in irrigated transplanted rice (*Oryza sativa*) using an optical sensor. *Precision Agriculture* **16**(4): 455–75.

Timsina J and Connor D J. 2001. Productivity and management of rice- wheat cropping systems : issues and challenges. *Field Crops Research* **69**: 93–132.