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Better crop establishment, residue recycling and diversification for sustaining non-basmati rice (*Oryza sativa*) in western IGP

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ABSTRACT

The conventional non-basmati rice (*Oryza sativa* L.) is neither economical nor sustainable in IGP. Therefore, an on-farm study was carried out at the farmer's field in Karnal district of Haryana to find out alternative by diversified crops having legume (summer mungbean) with the best tillage and residue management practices. The intensification through conservation agriculture (CA)-based crop management within the RW system (CTR–ZTWMb and DSR–ZTWMb) and beyond with diversification by maize (ZTMWMb and ZTMMuMb) gave statistically on par yield to conventional non-basmati rice (CTRW). Compared to CTRW, total water use was reduced by 0.8 and 14.8% in CTR–ZTWMb and DSR–ZTWMb, respectively. The total water use was significantly reduced by 53.9 to 60.8% with maize and soybean (ZTMWMb, ZTMMuMb, and ZTSWMb) over DSR–ZTWMb and CTRW. The net returns increased by ₹3.7–6.5 × 10^3/ha in CTR–ZTWMb and DSR–ZTWMb over the CTRW. In diversified systems, net returns increased by ₹10–16.5 × 10^3/ha with maize systems compared to three rice production scenarios. Similarly, in soybean, net returns enhanced by ₹4.6 × 10^3/ha over the CTRW systems. Moreover, there was a significant decrease in global warming potential (GWP) by 53.4–69.1, 53.3–69.0 and 46.9–64.8% was observed under ZTMWMb, ZTMMuMb and ZTSWMb, respectively over the three RW system treatments. These results demonstrate that crop diversification with the inclusion of maize and soybean with CA may be opted to improve crop and water productivity and farmer's income replacing traditional rainy (*kharif*) season non-basmati rice in Western Indo-Gangetic Plains (IGP).

Keywords: Conservation agriculture, Crop and water productivity, Maize, Rice-wheat system, Soybean

The green revolution facilitated the expansion of the area under rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) (RW) rotation and is now estimated to be about 14 million ha (mha) which is confined to Indo-Gangetic Plains (IGPs). During this period, the area of maize, pulses, and oilseeds drastically decreased in Punjab and Haryana (Rakshit *et al.* 2021). The region enjoys high economic growth but suffers from the deterioration of natural resources. The traditional RW system practices are not only increasing cultivation costs but also reducing wheat yield by 12–15% (Kakraliya *et al.* 2018). The over-exploitation of groundwater led to the decline in groundwater depth in north-western India by ~0.2 m per year, which accelerated by five-fold (1.0 m per year) between 2000 and 2006 (Jat *et al*. 2019a). The adverse environmental and economic impact of the rice-wheat cropping system in the north-western IGPs calls for immediate diversification through the introduction of more sustainable cropping systems. In Punjab and Haryana, approximately 2.5 mha area under non-basmati rice faces the challenges of non-availability of improved varieties and low yield. Therefore, the area can be diversified with alternative high-yield potential crops like maize.

Presently, the cultivation of the maize-wheat system is practiced in about 1.86 mha in the IGP (Jat *et al.* 2020). Conservation agriculture (CA) based maize-wheat/mustard with the integration of summer mungbean enhances productivity, profitability and water-use efficiency (Jat *et al.* 2020). Similarly, soybean can be the very potential to meet the projected demand for edible oil (47.7 million tonnes by 2025) and can reduce the import burden in the country (Rakshit *et al.* 2021). The maize and soybean-based system has been recommended in this region by many researchers but could be scaled up due to the non-involvement of the stakeholders in the technology development/evaluation process. Thus, the information on the integration of the diversified cropping system with precision water and nutrient management is scarce and especially at the farmers' field as participatory technology development. Therefore, a

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study was carried out on better crop establishment, residue recycling, and diversification which helps in sustaining non-basmati rice in western IGP. We hypothesized that CA-based diversified system development at farmer's fields may enhance crop and water productivity and net returns along with reducing environmental footprints and ultimately enhance the adoption of these systems to a scale.

MATERIALS AND METHODS

The field experiments were conducted at the farmer's field in Karnal district of Haryana during rainy (*kharif)* season of 2019 and 2020. The experimental sites have typically been dominated by the rice-wheat cropping system for the last 30 years, and have a semiarid sub-tropical climate with an average annual rainfall of 650–750 mm. The seasonal mean maximum temperature was 33.7ºC in both years. The seasonal mean minimum temperature was 23.4 and 22.7ºC and relative humidity remained at 61 and 58% in 2019 and 2020, respectively. The composite soil sample was drawn at 0–30 cm soil depth and analyzed with standard procedures at the end of the cropping season in June 2021. The soil of the experimental field was sandy to clay loam in texture with an organic carbon content of 0.59±0.01%, *p*H (1:2, soil:water) of 7.76±0.07, and EC of 0.5±0.1 dS/m. The field had low available nitrogen, and medium available phosphorus and potassium.

The experiment consisted of 6 treatments/cropping systems referred to as scenarios (Sc). These scenarios were placed at four farmers' fields and each location was treated as replication in a randomized complete block design. The net plot size was 400–450 m^2. The treatment details for different scenarios (Sc.) are given in Table 1.

Grain yield estimation: The grains were separated manually or with the help of a mini plot thresher. The grain yield of crops was testified at optimum grain moisture in respective crops and then the weight was converted into tonnes/ha. To express the comparable impact of treatments, productivity was calculated for rice equivalent yield using standard procedure.

Water use: The amount of irrigation water applied to each plot during the whole *kharif* season was measured using a water meter. The total amount of water applied (input water) was computed by summing the irrigation (I) water and effective rainfall (ER).

Production economics: The economics of different crops in rainy (*kharif*) seasons were calculated using variable costs including human labour, tractor operational charges, cost of production inputs, harvesting, and threshing, etc. The fixed cost is also taken into consideration which includes land rent and interest on working capital. The cost of human labour was based on labour days/ha assuming an 8-hour working day (350 ₹/day in 2019 and 360 ₹/day in 2020 as per the Govt. of Haryana). In the CTRW system, the rice residue was removed after combined harvesting by the farmers and sold out at ₹2500/ha. The net returns (NR) were calculated as the difference between the GR and the total cost (NR = GR−Total cost).

Environmental footprints: The GHGs emissions were calculated by using Climate Change Agriculture and Food Security (CCAFS)-Mitigation Options Tool-MOT.

$$\text{Global warming potential (GWP) (kg } CO_2\text{-eq/ha)} = CO_2 \text{ (kg/ha)} + N_2O \text{ (kg/ha)} \times 298 + CH_4 \text{ (kg/ha)} \times 34)$$

Table 1 Treatment details for different scenarios

Sc.	Cropping systems	Tillage	Crop establishment	Residue management	Nutrient management
Sc.1	Rice–wheat (CTRW)	Conventional tillage in both crops	Puddled transplanted rice-broadcast seeded wheat	Removal of rice and wheat residues (except stubbles of both)	Farmers fertilizer practice
Sc.2	Rice–wheat–mungbean (CTR–ZTWMb)	Conventional tillage in rice and zero tillage in wheat and mungbean	Puddled transplanted rice-zero till (happy seeder) wheat and mungbean	The full residue of rice and stubbles of wheat retained on the surface, full mungbean residues incorporated	Nutrient application based on precision tools (Nutrient Expert, Green Seeker)
Sc.3	Rice–wheat–mungbean (DSR–ZTWMb)	Zero tillage in all 3 crops	Direct seeded rice, ZT flat wheat, and mungbean	The full residue of rice, stubbles of wheat, and full residues of mungbean are retained on the soil surface	Same as Sc.2
Sc.4	Maize–wheat–mungbean (ZTMWMb)	Same as Sc.3	Permanent raised beds in all 3 crops	65% residue of maize, stubbles of wheat, and full residues of mungbean retained on the soil surface	Same as Sc.2
Sc.5	Maize–mustard–mungbean (ZTMMuMb)	Same as Sc.3	Same as Sc.4	65% maize residue, stubbles of mustard, and full residues of mungbean retained on the soil surface	Same as Sc.2
Sc.6	Soybean–wheat–mungbean (ZTSWMb)	Same as Sc.3	Same as Sc.4	35% residue of soybean, stubbles of wheat, and full residues of mungbean retained on the soil surface	Same as Sc.2

GHG emission intensity (GWP per unit of grain yield) = Total GWP was divided by the grain yield to obtain emission intensity.

Statistical analysis: The data that were recorded for different parameters were statistically analyzed using the analysis of variance technique for randomized complete block design. The least significant difference (LSD) test was used as a post hoc mean separation test (P<0.05) to decipher treatment effects.

RESULTS AND DISCUSSION

Rice equivalent yield (REY): The two-year on-farm study revealed that intensification of the RW system through CA-based crop management within the RW system (CTR–ZTWMb and DSR–ZTWMb) and beyond with diversification by maize (ZTMWMb and ZTMMuMb) gave statistically on par yield to rainy (*kharif)* season non-basmati rice. The CA-based soybean gave the statistically lowest rice equivalent yield (REY) during both years of experimentation (Table 2). The change in the REY across CA-based diversified cropping systems over the CTRW was 5.9, 2.0, 1.7, 0.6, and -12.0% on the pooled basis in CTR–ZTWMb, DSR–ZTWMb, ZTMWMb, ZTMMuMb, and ZTSWMb, respectively. However, the REY was increased by 2.0 and 5.9% by CA-based RW systems (DSR–ZTWMb and CTR–ZTWMb) and by 0.6 and 1.7% with CA-based maize systems (ZTMMuMb and ZTMWMb) over the CTRW which was statistically similar. The similar or higher yield observed in DSR compared to TPR was due to improved management practices such as suitable cultivars, planting methods, precise water, and nutrient management, and effective and efficient weed management. Similar results were reported by many researchers in this ecology (Choudhary *et al.* 2018, Kakraliya *et al.* 2018). On the other side, CA-based maize (ZTMWMb and ZTMMuMb) systems have the potential to compete with non-basmati rice for crop productivity owing to the availability of better cultivars with improved weed and nutrient management practices. The permanent beds (PBs) reduced climatic risks such as excess rainfall, dry spell, and fewer crops logging and lodging and ensured optimum plant population, better water regime, active soil aeration, lower weed pressure, better soil physical health, and improved nutrient and water use efficiency resulting in luxury growth of maize in diversified systems. These results are in close conformity with the finding of earlier researchers (Choudhary *et al.* 2018, Kumar *et al.* 2018, Jat *et al.* 2020a) ascribed that the higher yield of maize was recorded in ZT permanent beds (PBs).

Water use: The significantly higher total water use was recorded in CTRW while significantly lower total water use was recorded in ZTMMuMb and ZTMWMb, respectively during both the year of study (Table 2). The total water use was reduced by 0.8 and 14.8% in CTR–ZTWMb and DSR–ZTWMb, respectively over the CTRW. On the other side, the total water use was significantly reduced by 53.9

Table 2 Effect of different cropping systems, tillage and crop establishment practices on yield, water use and economics in *kharif* crops

Cropping system scenarios	Rice equivalent yield (t/ha)			Total water use (ha-mm)			Cost of cultivation ($\times 10^3$ ₹/ha)			Net returns ($\times 10^3$ ₹/ha)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
CTRW	6.45	6.53	6.49	2010	1895	1953	56.3	57.5	56.9	63.2	67.1	65.1
CTR–ZTWMb	6.82	6.93	6.87	2002	1874	1938	57.7	58.0	57.8	66.1	71.4	68.8
DSR–ZTWMb	6.59	6.66	6.62	1697	1629	1663	51.4	49.4	50.4	68.2	75.0	71.6
ZTMWMb	6.35 (6.55)	6.85 (6.91)	6.60 (6.73)	781	750	766	47.5	45.4	46.4	75.2	89.6	82.4
ZTMMuMb	6.35 (6.55)	6.71 (6.78)	6.53 (6.66)	770	752	761	47.4	46.1	46.7	75.3	86.4	80.8
ZTSWMb	5.36 (2.62)	5.96 (2.87)	5.66 (2.75)	786	757	772	42.3	40.4	41.3	61.4	78.1	69.7
SEm(±)	0.23	0.18	0.15	26	24	88	0.3	0.3	0.9	4.2	3.4	2.6
LSD (P=0.05)	0.68	0.54	0.43	79	72	255	0.9	0.8	2.7	NS	10.2	7.6
Year-1			6.32			1341			50.4			68.3
Year-2			6.61			1276			49.4			77.9
SEm±			0.05			29			0.3			0.9
LSD (P=0.05)			NS			NS			NS			NS
Interaction (Y × CS)												
SEm±			0.10			59			0.63			1.76
LSD (P=0.05)			NS			NS			NS			NS

*The figure in the parenthesis represents the absolute grain yield of the respective *kharif* crops. Treatment details are given in Table 1.

and 60.8% with CA-based diversified systems (ZTMWMb, ZTMMuMb and ZTSWMb) over DSR-ZTWMb and CTRW, respectively. Ram *et al.* (2012) also reported lower water use and high water productivity in bed-planted soybean in western IGP.

Economic profitability

Cost of cultivation: Higher cost of cultivation of *kharif* crop was recorded in CTR–ZTWMb which was statistically at par with CTRW while the lowest was recorded in ZTSWMb (Table 2). The cost of cultivation was changed by +1.6 and -11.4% in CTR–ZTWMb and DSR–ZTWMb, respectively over the CTRW. The cultivation cost was significantly decreased by ₹3.9×10^3/ha and ₹10.3 × 10^3/ha with maize and by ₹9.1×10^3/ha and ₹15.6×10^3/ha with soybean over DSR–ZTWMb and CTRW, respectively. The lower production cost was recorded in CA-based diversified systems, even crop residue input cost was added into that compared to RW systems. Jat *et al.* (2019a) also reported the adoption of a CA-based diversified system with maize and the integration of precision water and nutrients management significantly reduced the cost of tillage and inputs (water and fertilizers) as compared to CTRW.

Net returns: In the first year, the net returns in rainy (*kharif)* season crops were not influenced by various cropping systems scenarios. However, during the second year and on a pooled basis, significantly higher net returns were recorded in diversified systems with maize (ZTMWMb and ZTMMuMb) over the RW systems (CTRW, CTR–ZTWMb, and DSR–ZTWMb) (Table 2). The net returns increased by ₹3.7–6.5×10^3/ha in CA-based systems (CTR–ZTWMb and DSR–ZTWMb) over the CTRW. The net returns were increased by ₹10–16.5×10^3/ha in maize systems (ZTMWMb and ZTMMuMb) over the RW systems (DSR–ZTWMb and CTRW). In soybean, the net returns were changed by ₹-1.9 and 4.6 × 10^3/ha over DSR–ZTWMb and CTRW, respectively. CA-based diversified systems with ZT and permanent bed establishment gained higher net retunes due to the cumulative effect of lower production cost of tillage, fertilizers, and irrigation, and produced higher grain yield of crops compared to non-basmati rice. These results of the economic profits from maize-based rotations are in close conformity with those reported by many early studies (Parihar *et al.* 2016, Jat *et al.* 2020a). Mishra and Singh (2009) reported that ZT soybean-wheat cropping systems gave higher net returns due to lower cost of cultivation and higher yield of soybean under CA-based improved management.

Partial factor productivity of nitrogen: Significantly higher Partial factor productivity (PFP) of applied nitrogen (N) was recorded in ZTSWMb while the significantly lower PFP of N applied was recorded in CTRW during both the year of experimentation (Table 3). Compared to CTRW, significantly increased PFP of N applied by 33.0 and 36.6% with CTR–ZTWMb and DSR–ZTWMb, respectively. Similarly, the PFP of N applied increased significantly in diversified systems by 42.3, 39.8 and 176.1% with ZTMWMb, ZTMMuMb, and ZTSWMb, respectively over the CTRW. Diversification with the inclusion of maize or soybean in the place of rice reduced the N-fertilizers dose and enhanced the PFP of N. Furthermore, the biological nitrogen fixation by soybean

Table 3 Effect of different cropping systems, tillage and crop establishment practices on PFP of nitrogen (N), global warming potential and emission intensity in *kharif* crops

Cropping system scenarios	PFP_N (kg/kg N applied)			Global warming potential (kg CO_2 eq/ha)			Emission intensity (kg CO_2 eq/t yield)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
CTRW	35.0	35.4	35.2	6664	6479	6571	1.05	1.01	1.03
CTR–ZTWMb	47.7	48.4	48.1	6376	7014	6695	0.95	1.04	1.00
DSR–ZTWMb	46.5	47.0	46.8	4352	4537	4444	0.67	0.69	0.68
ZTMWMb	48.8	51.5	50.1	2132	2006	2069	0.33	0.29	0.31
ZTMMuMb	48.8	49.7	49.2	2118	2031	2075	0.32	0.31	0.32
ZTSWMb	92.9	101.5	97.2	2375	2344	2359	0.91	0.82	0.86
SEm(±)	2.9	2.5	3.4	116	143	320	0.05	0.05	0.05
LSD (P=0.05)	8.6	7.5	9.7	350	432	926	0.14	0.14	0.14
Year-1			53.3			4003			0.70
Year-2			55.6			4069			0.69
SEm±			1.1			107			0.02
LSD (P=0.05)			NS			NS			NS
Interaction (Y × CS)									
SEm±			2.2			214			0.03
LSD (P=0.05)			NS			NS			NS

Treatment details are given in Table 1.

supplements the N demand and cut-down the dose of N-fertilizer. Crop diversification with residue recycling build-up the soil organic matter and increased readily mineralized organic soil N suggesting the potential for reducing fertilizer N rates to increase the PFP of N. Similar study was done by Parihar *et al.* (2016) and Ram *et al.* (2012). The higher yield with higher PFP of applied N was registered in rice (CTR–ZTWMb and DSR–ZTWMb) by the adoption of Nutrient Expert and Green seeker-based precision nitrogen management practices at the place of farmer's fertilizers practices (CTRW).

Environmental footprints: Significantly higher global warming potential (GWP) and emission intensity (EI) were recorded in CTR–ZTWMb which was statistically at par with CTRW while significantly lower in ZTMWMb and ZTMMuMb during both the year of study (Table 3). As compared to CTRW, the GWP changed by +1.9 and -32.4% while EI decreased by 2.9 and 34% on the pooled basis in CTRW–ZTWMb and DSR–ZTWMb, respectively.

In CA-based diversified systems, the significantly decreased GWP and EI by 53.4–69.1 and 54.4–69.9% respectively in ZTMWMb and by 53.3–69 and 52.9–68.9%, respectively in ZTMMuMb. In ZTSWMb, the GWP was significantly decreased by 46.9–64.8% but the EI was changed by -16.5 to + 26.5% over the RW systems (CTRW and DSR–ZTWMb). The DSR reduced methane emissions by eliminating prolonged soil anaerobic conditions during land preparation. The CA-based diversification with maize and soybean has the potential to reduce GWP and emission intensity because the higher crop yield with less GHGs emissions under better crop establishment, zero-tillage, residues retention, and precision nutrients and water management significantly reduces all the GHGs like CO_2, CH_4, and N_2O as compared to RW systems. The soybean has less water requirement and it could meet its nitrogen requirement through biological N_2 fixation. Jat *et al.* (2019b) reported lower carbon footprints and advocated maize-wheat/mustard systems as efficient and clean.

Intensifications of the RW system within (through CA-based management) or beyond (through CA-based maize and soybean) proved a significantly better alternative for higher crop productivity at lower cultivation cost, improved water productivity, net returns and partial factor productivity of applied nitrogen, reduced global warming potential and emission intensity over the CTRW with traditional practices. Thus, the on-farm study revealed that a set of CA-based improved practices by integration of precision inputs management with a diversified cropping system could address the multiple challenges of declining crop productivity, depleting water resources, decreasing farm profitability and increasing environmental footprints in traditional RW system of Western Indo-Gangetic Plains.

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