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Productivity, profitability and input-use efficiency of direct-seeded rice (*Oryza sativa*) under conservation agriculture

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ABSTRACT

A field experiment was conducted during *kharif* 2016-17 at ICAR-Indian Agricultural Research Institute, New Delhi to assess the long term impact of conservation agriculture (CA) on productivity, profitability and input-use efficiency of rice (*Oryza sativa* L.) under a rice-wheat cropping system (RWCS). Pooled results revealed that rice grain yield under the CA-based zero till direct seeded rice (ZTDSR) + mungbean residue (MR) – zero till wheat (ZTW) + rice residue (RR) – zero tilled summer mungbean (ZTM) + wheat residue (WR) both with 100% N (4.9 t/ha) and 75% N (4.8 t/ha) was statistically comparable to the conventional practice, i.e. transplanted puddled rice (TPR) – conventional till wheat (CTW) (5.2 t/ha) and TPR – ZTW (5.4 t/ha). Although rice grain yield under ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] was ~5.7% lower compared to farmers' practice TPR–CTW, net returns of rice (₹ 41.1×10^3 / ha) was 119.5% higher compared to TPR-CTW, chiefly due to the lower cost of cultivation of ZT-DSR (₹ 47.5×10^3 / ha) as compared to CT-TPR (₹ 74.8×10^3 /ha). Partial factor productivity of NPK was highest under the CA treatment ZTDSR+MR–ZTW+RR–ZTM+WR [75% N] (32 kg grain/kg NPK) while ZTDSR+MR–ZTW+RR–ZTM+WR [75% N] [100% N] observed the highest irrigation water use efficiency (0.57 kg/m^3). Thus, the novel CA practice ZTDSR+MR–ZTW+RR–ZTM+WR can provide comparable rice yields with higher net returns and nutrient (75% N) and irrigation use efficiencies compared to conventional farmers practice TPR–CTW and hence its adoption may be recommended.

Key words: Conservation agriculture, Irrigation water use efficiency, Nutrient use efficiency, Productivity, Profitability, Rice

The conventional system of cultivating rice (*Oryza sativa* L.) and wheat crops leads to degradation of soil and water resources, leading to an impending threat to the system sustainability (Gupta and Seth 2007, Gathala *et al*. 2013, Nath *et al*. 2017). The widely adopted transplanted puddled rice (TPR) with continuous submergence invites several problems, viz. higher labour, energy, and water requirement and cultivation cost, soil degradation, subsoil compaction, methane emission, weed shift and resistance (Das 2001, Susha *et al*. 2018, Das *et al*. 2020). There are reports (Kukal *et al*. 2005, Sudhir-Yadav *et al*. 2011) that rice can withstand soil water tension up to 10–20 kPa, therefore, disproving the necessity of continuous water stagnation to maintain optimum rice yields (Humphreys *et al*. 2010). Further studies (Malik and Yadav 2008) have also established successful cultivation of dry seeded rice in non-puddled soil with proper irrigation. But, there are reports of yield penalty under dry seeding of rice with alternate wetting and drying (AWD) method of water management (Bhushan *et al*. 2007, Choudhury *et al*. 2007).

Conservation agriculture (CA) aims at conserving natural resources through increased input-use efficiency and judicious management of existing soil, water, and biological resources augmented with external inputs (Das *et al*. 2018). Direct-seeded rice (DSR) has several advantages over transplanting such as early maturity, less water and labour requirement, better soil aeration with improved physical, chemical and biological properties for crops grown in succession (Bhattacharyya *et al*. 2013, Gathala *et al*. 2013, Bhattacharyya *et al*. 2015), lesser greenhouse gases (GHGs) emissions (Das *et al*. 2013), and high economic returns (Baghel *et al*. 2020). The extent of benefits of CA based technologies varies across sites therefore technologies should be optimized and refined to best suit to local environments (Hobbs 2007, Kienzler *et al*. 2012). Keeping these facts in view, the present investigation was undertaken to assess the long term impacts of CA on productivity, profitability and resource use efficiency of rice in a rice-wheat cropping system in the northern Indo-Gangetic Plains (IGP) of India.

MATERIALS AND METHODS

A two year field experiment (2016-17) was conducted at Division of Agronomy, ICAR-Indian Agricultural Research

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Institute, New Delhi (28°64′ N latitude, 77°15′ E longitude and altitude of 228 meters amsl) during rainy (*kharif*), winter (*rabi*) and summer 2016-17 and 2017-18. The climate of the site is characterized by sub-tropical semi-arid climate having hot dry summers in May and June (mean maximum temperature of 40-45°C) and extreme cold winter in December and January (mean minimum temperature of 2°C). The total annual rainfall during the cropping period (*kharif* – *rabi* – summer) of 2016-17 and 2017-18 was 1341.4 and 816.4 mm respectively. Soil was Inceptisol (order), having clay loam texture in upper 30 cm layer and loamy texture in deeper layers. The present experiment was laid out in a randomized complete block design (RCBD) with eleven treatments replicated thrice. The CA treatments included cropping sequence of zero till direct-seeded rice (ZTDSR), zero till wheat (ZTW), zero tilled summer mungbean (ZTM) and residue management combinations, viz. brown manuring (BM), wheat residue (WR), rice residue (RR) and mungbean residue (MR). The CT treatments included transplanted rice (TPR) – conventionally tilled wheat (CTW) and TPR–ZTW. Turbo happy seeder (THS) was used for sowing of zero tillage DSR using 20 kg seed/ha at a row-spacing of 20 cm in undisturbed soil. A pre-sowing irrigation was given to ensure good germination in DSR. Brown manuring (BM) was practised in DSR with *Sesbania aculeata* (Dhaincha) and knocked down with the selective herbicide bispyribac-Na at 0.025 kg/ha. Wheat residue @ 2 t/ha (20% w/w) and rice residue @ 4 t/ha (40% w/w) was retained on the soil surface after harvest. TPR involved one disking (disc plough), one harrowing and two cultivator operations, followed by planking under aerobic soil conditions. Seedlings from the nursery were transplanted manually into puddled soils, at 20 cm × 10 cm spacing. The recommended fertilizer dose nitrogen was 120 kg/ha while treatments with 75% N received 90 kg/ha, with uniform P_2O_5 and K_2O application of 60 and 40 kg/ha respectively in both rice and wheat crop. ZTDSR required 14-15 irrigations (6 cm) while TPR used 21-22 irrigations (7 cm depths).

Threshed and cleaned rice grains from each net plot was weighed and expressed in t/ha. Grain yields were represented at 12% moisture. The yield of above ground total dry matter (biological yield) per net plot was recorded after sun drying and before threshing. Gross returns, net returns and benefit cost ratio were calculated as per standard equations (Nath *et al*. 2017). Partial factor productivity (PFP) of fertilizer applied (NPK) for rice was calculated by dividing grain yield with total fertilizer dose ($N+P_2O_5+K_2O$). Irrigation water use efficiency (IWUE) was calculated as the dry grain yield (kg/ha) divided by the irrigation water applied (m^3/ha) (Ibragimov *et al*. 2011). The statistical analysis (Das 1999) was performed using the randomized complete block design analysis in SAS 9.3 (Indian NARS Statistical Computing Portal). To separate treatment means within each measured parameter, Least significant difference (LSD) post hoc test was performed at P=0.05. Pooled analysis was performed considering year as a random effect (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Rice crop productivity: The grain and straw yields of rice exhibited significant variation under CA and CT treatments (Table 1). Rice grain yield (pooled) was significantly higher under the treatment TPR–ZTW (5.4 t/ha), which was comparable with the farmers' practice TPR–CTW (5.2 t/ha) and the triple ZT with residue (+R) systems, viz. ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] (4.9 t/ha) and ZTDSR+MR–ZTW+RR–ZTM+WR [75% N] (4.8 t/ha). Similarly, rice straw yields were significantly higher under TPR–ZTW (8.87 t/ha) which was at par with TPR–CTW, ZTDSR+MR–ZTW+RR–ZTM+WR [100 and 75% N] and ZTDSR–ZTW–ZTM (T_7). Rice grain yields under farmers' practice TPR–CTW was 5.7% higher over the superior CA practice ZTDSR+MR–ZTW+RR–ZTM+WR [100% N]. Furthermore, average TPR yields (T_9 and T_8) were about

Table 1 Influence of CA practices on grain yield, straw yield, harvest index (HI) and irrigation water use efficiency (IWUE) of rice in a RWCS (pooled values of 2 years)

	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)	IWUE (kg/m^3)
Year (Y)				
Y_1 : 2016-17	4.0^{b}	7.1^{b}	35.9^{a}	0.43^{b}
Y_2: 2017-18	4.9^{a}	8.0^{a}	37.6^{a}	0.49^{a}
LSD (P=0.05)	0.3	0.21	NS	0.03
Treatments (T)				
T_1 : ZTDSR–ZTW (100% N)	4.5^{cd}	7.6^{bcd}	37.2^{a}	0.51^{abc}
T_2 : ZTDSR+BM–ZTW (100% N)	3.8^{de}	6.6^{d}	36.3^{a}	0.43^{c}
T_3 : ZTDSR+WR–ZTW+RR (75% N)	3.9^{de}	6.9^{cd}	35.9^{a}	0.44^{c}
T_4 : ZTDSR+WR–ZTW+RR (100% N)	3.9^{de}	6.9^{cd}	36.0^{a}	0.45^{bc}
T_5 : ZTDSR+WR+BM–ZTW+RR (75% N)	3.8^{e}	6.6^{d}	36.1^{a}	0.43^{cd}
T_6 : ZTDSR+WR+BM–ZTW+RR (100% N)	3.8^{de}	6.7^{d}	36.0^{a}	0.44^{c}
T_7 : ZTDSR–ZTW–ZTM (100% N)	4.6^{bc}	7.9^{abc}	37.0^{a}	0.53^{ab}
T_8 : ZTDSR+MR–ZTW+RR–ZTM+WR (75% N)	4.8^{abc}	8.2^{ab}	36.7^{a}	0.55^{a}
T_9 : ZTDSR+MR–ZTW+RR–ZTM+WR (100% N)	4.9^{abc}	8.3^{ab}	37.2^{a}	0.57^{a}
T_{10} : TPR–ZTW (100% N)	5.4^{a}	8.9^{a}	38.0^{a}	0.35^{de}
T_{11} : TPR–CTW (100% N)	5.2^{ab}	8.7^{a}	37.5^{a}	0.33^{e}
LSD (P=0.05)	0.3	0.6	1.7	0.05

Values within a column followed by the different lowercase letters indicate a significant difference at P<0.05 using the LSD method.

26% higher over the average DSR yields ($T_1 - T_9$). Lower yield performance of DSR might have been due to higher soil moisture stress, seedling mortality and higher weed pressure compared to TPR. Moreover, the double ZT (+R) treatments having wheat residue retention in rice crop invited higher nematode infestations which further affected rice crop growth and yield. Nematode incidence was minimal in the triple ZT (+R) treatments having mungbean residue in rice as well as without residue treatments. The harvest index of rice ranged from 35.9-38.0%, however the differences were non-significant. Jat *et al.* (2014) reported that rice yields in ZTDSR–ZTW+RR out-yielded the TPR system in the sixth and seventh year of study.

Rice production economics: Economic analysis (pooled) revealed that the cost of cultivation, gross returns, net returns and B:C ratio of rice differed noticeably under CA and CT practices (Table 2), which was directly dependant on the price of crop produce and cost incurred on various inputs, tillage and residue management under different treatments.

Table 2 Influence of CA practices on economics of rice in a RWCS (pooled values of 2 years)

	COC ($\times 10^3$ ₹/ha)*	GR ($\times 10^3$ ₹/ha)†	NR ($\times 10^3$ ₹/ha)‡	B:C
Year (Y)				
Y_1 : 2016-17	51.1^{b}	69.4^{b}	18.3^{b}	0.39^{b}
Y_2: 2017-18	58.6^{a}	89.8^{a}	31.2^{a}	0.58^{a}
LSD (P=0.05)		3.9	3.9	0.08
Treatments (T)				
T_1 : ZTDSR–ZTW (100% N)	47.3	80.0^{cd}	32.6^{ab}	0.69^{a}
T_2 : ZTDSR+BM–ZTW (100% N)	49.2	68.5^{e}	19.3^{c}	0.38^{b}
T_3 : ZTDSR+WR–ZTW+RR (75% N)	53.5	70.4^{de}	16.9^{c}	0.30^{b}
T_4 : ZTDSR+WR–ZTW+RR (100% N)	53.8	71.2^{de}	17.4^{c}	0.31^{b}
T_5 : ZTDSR+WR+BM–ZTW+RR (75% N)	55.4	68.0^{e}	12.7^{c}	0.22^{b}
T_6 : ZTDSR+WR+BM–ZTW+RR (100% N)	55.7	69.1^{de}	13.4^{c}	0.23^{b}
T_7 : ZTDSR–ZTW–ZTM (100% N)	44.1	83.2^{bc}	39.1^{a}	0.89^{a}
T_8 : ZTDSR+MR–ZTW+RR–ZTM+WR (75% N)	47.2	86.1^{abc}	39.0^{a}	0.82^{a}
T_9 : ZTDSR+MR–ZTW+RR–ZTM+WR (100% N)	47.5	88.6^{abc}	41.1^{a}	0.86^{a}
T_{10} : TPR – ZTW (100% N)	74.7	96.7^{a}	22.0^{bc}	0.29^{b}
T_{11} : TPR – CTW (100% N)	74.7	93.4^{ab}	18.7^{c}	0.25^{b}
LSD (P=0.05)		4.7	4.7	0.09

Values within a column followed by the different lowercase letters indicate a significant difference at P<0.05 using the LSD method; *COC = Cost of Cultivation, †GR = Gross returns, ‡NR = Net returns.

Cost of cultivation (₹/ha) of rice was substantially higher (57%) under TPR (₹ 74.7 × 10^3/ha) compared to the CA system ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] (₹ 47.5 × 10^3 /ha). Higher production cost of TPR could be ascribed to additional charges of tillage, labour and irrigation. Net returns of rice were significantly higher in the triple ZT system ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] (₹ 41.1 × 10^3/ha) which was at par with ZTDSR+MR–ZTW+RR–ZTM+WR [75% N], ZTDSR–ZTW–ZTM and ZTDSR–ZTW. The CA system ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] recorded 120% higher net returns over the farmers' practice TPR–CTW system. Highest B:C ratio was obtained in triple ZT (–R) system ZTDSR–ZTW–ZTM (0.89) being comparable with ZTDSR+MR–ZTW+RR–ZTM+WR and ZTDSR–ZTW. The results are in conformity with the findings of Nath *et al*. (2017) who also obtained better economic returns under CA compared to CT practice. Lower rice yields and higher cost of residue retention, led to narrower net returns under double ZT (+R) systems ($T_2 - T_6$). These findings pointed towards the scope for improving rice yields through good crop husbandry under DSR system.

Nutrient-use efficiency and irrigation water-use efficiency: Nutrient-use efficiency (NUE) was worked out in terms of partial factor productivity (PFP) i.e. rice grain yield produced per unit application of N (PFP_N) and total nutrients (PFP_{NPK}) through fertilizers. Pooled results revealed that significantly higher value of PFP_N (Fig 1a) was obtained under the CA treatment ZTDSR+MR–ZTW+RR–ZTM+WR [75% N] which was 22% higher over TPR–CTW. The CA treatment ZTDSR+MR–ZTW+RR–ZTM+WR [75% N] also recorded 10% higher PFP_{NPK} in rice (Fig 1b) over the farmers' practice TPR–CTW. Higher PFP_{NPK} in the triple ZT (+R) systems could be attributed to the enrichment of soil health and fertility through crop residues which achieved comparable grain yields with 25% lower nitrogen doses. Maximum IWUE (kg grain/m^3 water) in rice (Table 1) was recorded in the CA treatment ZTDSR+MR–ZTW+RR–ZTM+WR [100% N] (0.57) which was at par with ZTDSR+MR–ZTW+RR–ZTM+WR [75% N], ZTDSR–ZTW–ZTM [100% N] and ZTDSR–ZTW [100% N]. Significantly lower IWUE in rice was witnessed in farmers' practice TPR– CTW (0.33) and TPR–ZTW (0.35). Average IWUE in CA systems with ZTDSR ($T_1 - T_9$) was 42 % higher than CT-TPR systems (T_{10} and T_{11}) owing to significantly lower water requirement in DSR (14-15 irrigations) compared to TPR (21-22 irrigations). Similar findings were obtained by Saad *et al*. (2015) who observed remarkably higher IWUE (kg grain/m^3 water) of wheat under CA compared to CT.

Thus it can be concluded that the conservation agriculture based triple ZT (+R) system ZTDSR+MR–ZTW+RR–ZTM+WR with 100% N can provide comparable rice grain and straw yields with the farmers' practice TPR–CTW. Moreover, cost of cultivation was 57% lower in ZT-DSR compared to the CT-TPR system which led to increase in net income to the tune of 120% (₹ 22400/ha).

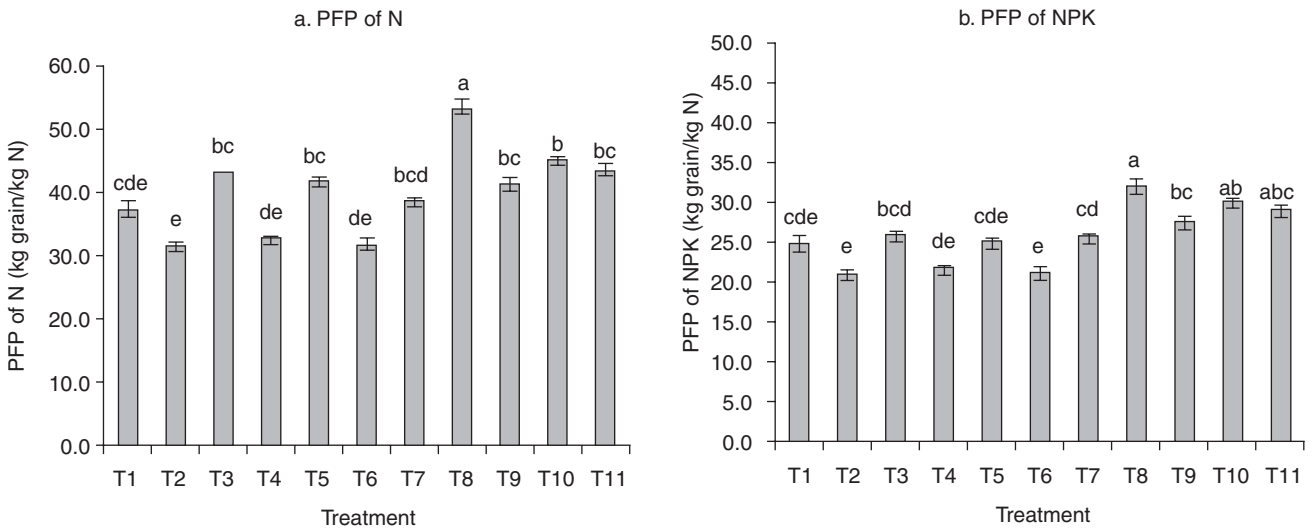

Fig 1 Effect of CA practices on partial factor productivity (PFP) of (a) N and (b) total NPK in rice (pooled value of 2 years). Vertical bars indicate standard errors of the respective treatments across the replications. Different lowercase letters of the English Alphabets shown above the columns indicate that columns with different letters are significantly different at $P<0.05$ (using the LSD method).

The ZT-DSR crop raised with lesser number of irrigations (average 7 irrigations) led to significantly higher irrigation water-use efficiencies which was highest in the triple ZT (+R) system, viz. ZTDSR+MR–ZTW+RR–ZTM+WR (0.57 kg/m^3) and considerably lower in conventional systems TPR– CTW and TPR–ZTW. Nutrient-use efficiency in terms of partial factor productivity was higher in the triple ZT (+R) systems, viz. MR + ZTDSR – RR + ZTW – WR + ZTM with 75%/100% N compared to the conventional TPR and ZT (-R) systems.

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