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Weed dynamics, wheat (*Triticum aestivum*) yield and irrigation water-use efficiency under conservation agriculture

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The continued monoculture of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system (RWS) has resulted in yield stagnation, degradation of soil physical properties, loss of soil fertility and occurrence of multi-nutrients deficiency in Indo-Gangetic plains (IGP) (Jat *et al*. 2016, Baghel *et al.* 2020). Recent development of extra-short duration pigeon pea (*Cajanus cajan*) varieties such as ICPL 85010 (125–130 days), Pusa 855 (135–140 days), and Pusa Arhar 16 (120 days) has paved the way for sustainable diversification of RWS (Dahiya *et al*. 2002, Das *et al*. 2016, 2018). Conservation agriculture (CA) is a practice adopted over 205 million hectare (mha) area worldwide and aimed to conserve soil and water, mitigate adverse climate effects, and sustain production (Das *et al.* 2014, Kassam *et al.* 2022). Weed is one of the major constraints in both conventional till (CT) and zero till (ZT) systems, causing yield losses (Das 2001). Under CA, most weed seeds remain in the upper soil layer and residue retention restricts light availability for weed seed germination (Chauhan *et al*. 2012). These factors govern weed shift under CA system and hence its knowledge is essential to formulate effective weed management strategy (Govindasamy *et al*. 2020). CA also augments crop productivity and improves resource-use efficiency (Das *et al*. 2016, 2018). Therefore, this experiment was designed to evaluate the effect of tillage, crop residue retention and N application on weed interference, crop productivity, profitability and resource-use efficiency in wheat under a long-term CA-based pigeon pea-wheat system.

This study was conducted at ICAR-Indian Agricultural Research Institute, New Delhi, India during winter (*rabi*) 2021–22 in the 12th year of a long-term CA experiment initiated in 2010. Soil was sandy clay loam in texture (sand 48%, silt 24%, clay 28%) having *p*H 8.10–8.44, EC 0.22–0.29 dS/m, Walkley and Black C 6.5–9.7 g/kg, $KMnO_4$ oxidizable N 253.7–291.7 kg/ha, 0·5 M $NaHCO_3$ extractable P 73–95 kg/ha and 1 N NH_4OAc extractable K 436.2–599.8 kg/ha at 0–15 cm soil depth. Treatments were conventional till flatbed (CT), zero till (ZT) permanent narrow bed with and without residue (PNBR and PNB), broad bed with and without residue (PBBR and PBB), and flat bed with and without residue (PFBR and PFB). Further, the residue treatments had 75% and 100% of the recommended N for wheat, (i.e. PNBR75N, PNBR100N; PBBR75N, PBBR100N; PFBR75N, PFBR100N) during 2021–22. Weeds were counted and their dry weight was recorded from different treatments at 60 DAS. To evaluate changes in weed flora due to CT and CA, an area of 1 m × 1 m was randomly selected replication-wise across treatments and kept undisturbed and no herbicide was applied throughout crop growing period. Ear-bearing tillers were counted from three rows of 1.0 m length in each treatment. Grain yield was estimated from the net plot area of 5 m^2 and 7 m^2 in flat and raised beds, respectively. Irrigation water was supplied as per moisture requirement of a treatment. Irrigation water productivity was calculated as per Das *et al*. (2018). Weed density and dry weight were transformed through square-root method (Das 1999) before analysis of variance (ANOVA). Data on crop productivity, profitability, and resource-use efficiency were subjected to ANOVA in a randomized completed block design using OPSTAT and Tukey's HSD comparison was done.

Weed interference: Weed flora in an experimental wheat field comprised of *Phalaris minor* Retz. (grassy weeds); *Chenopodium album* L., *Coronopus didymus* L., *Malva parviflora* L., *Melilotus indica* L., *Parthenium hysterophorus* L., *Sonchus oleraceous* L., *Spergula arvensis* L., (broad-leaved weeds); and *Cyperus esculentus* L. (Sedge). Tillage (T), residue (R), and nitrogen (N), i.e. TRN management practices significantly influenced weed density at 60 DAS (Table 1). Grassy weed density was higher in PBB, got significantly reduced in PFBR75N. Broad-leaved weeds

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(BLW) and sedge densities were found significantly higher in CT. Hence, the total weed density was significantly higher in CT and lowest in permanent flat bed with residue and 75 and 100% N application, (i.e. PFBR75N and PFBR100N). Compared to CT, the PFBR75N led to 50% and 97.6% reduction in grassy and BLW weed population, respectively at 60 DAS. CT treatment had highest weed population, whereas PBB and PNB showed highest weed dry weight, which was 53.2 and 42.5% higher than in CT, respectively. Both PFBR100N and PFBR75N treatments were found more effective in reducing the overall weed density, and the next best treatments could be PBBR75N, PBBR100N, PNBR100N, and PFB. CT treatment had higher broad-leaved, sedge, and total weed densities, whereas, grassy weed infestation in CT and ZT treatments were comparable except in PFBR75N. Our results corroborated with Chhokar *et al*. (2007) and Nath *et al*. (2015). Frequent tilling under CT favoured germination and profuse tuberization of *C. esculentus*. Besides, favorable environmental conditions such as higher soil temperature during rainy (*kharif*) to the winter (*rabi*) season transition period, porous top soil due to tillage might facilitate sedges emergence.

Wheat yield attributes, yield and net benefit:cost: The CA-based systems led to significant improvement in yield attributes (EBT/m), grain yield and net returns (Table 2). The PBBR100N registered significantly higher ear-bearing tillers, and grains per spike than PFB and CT. Rest treatments were comparable with it on ear-bearing tillers, and PBBR75N, PNBR100N, PBB and PNBR75N were comparable with it on grains/spike. CA treatments showed 18.3–28.3% higher EBT/m and 5.9–27.6% higher grains/spike than CT. The ZT practice with or without residue improved wheat grain yield by 8.1–14.9% over CT. Among them, PFBR100N led to significantly higher grain yield (5.37 tonnes/ha). These treatments when supplemented with 100% or 75% N were comparable on yield attributes and yield. The loss of moisture from the soil surface through evaporation is faster in tilled soils resulting in poor germination, uneven crop plant stands and reduced crop development and yield under CT (Das *et al*. 2020). However, better tillering, higher grains/spike, and better weed suppression contributes to higher yield under CA (Nath et al. 2015, Nandan *et al*. 2020). Contrast analysis on wheat grain yield showed that among ZT bed systems, the treatments with residue retention outperformed the treatments without residue; 100% N as good as 75% N on yield parameters, indicating a saving of 25%N in wheat. The inclusion of pigeon pea as a legume component in this CA-based crop diversification could augment N reserve in the soil and reduce the N requirement (Powlson *et al*. 2016). All ZT bed systems with and without residue retention were comparable with each other and resulted in significantly higher net B:C (1.96–2.31) by 24.8–47.1% than CT. CT wheat incurred higher cost of cultivation than other practices due to cost of tillage operations for land preparation (Aryal *et al*. 2014). CA-based practices with residue retention also incurred slightly higher cost due to cost of residue, but the enhanced yield obtained could compensate that and led to higher net B:C.

Water productivity/use efficiency: Among ZT permanent bed systems (Table 2), the treatments with residue consumed less water than treatments having no residue. CT practice had the highest irrigation water use. CA-based residue retention treatments registered 9.0–20.6% lower irrigation water use than CT, and thereby led to increased irrigation water productivity by 25.2–43.9% over CT. Das *et al*. (2014) reported that CA system had 14% lower water consumption in wheat and 30% higher water-use efficiency than CT. ZT could improve soil structure, which is associated with greater water retention, improved infiltration and lower total water usage (Erenstein 2003). Contrast analysis on irrigation water productivity, showed the superiority of CA over CT whereas effect of 75 N and 100 N was comparable (P>0.05).

This study showed that PBBR100N and PFBR100N gave a comparable wheat yield, net B:C but PBBR100N was superior to PFBR100N on irrigation water productivity and wheat yield attributes, namely, EBT/m and grains/spike. The 100 N and 75 N were compared in this study after 12 years of CA with respect to most of the above-mentioned

Table 1 Category-wise weed density and dry weight in wheat under the fixed plot study across the treatments at 60 DAS

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	Grassy	Broad-leaved	Sedge	Total	Grassy	Broad-leaved	Sedge	Total
CT	1.6‡ (2)^{ab}†	3.6 (12.3)^{a}	11.0 (121)^{a}	11.7(135.3)^{a}	2.76 (7.5)^{abc}	1.02 (0.55)^{ab}	2.41 (5.3)^{a}	3.7 (13.4)^{ab}
PNB	2.1 (4)^{ab}	3.9 (14.7)^{ab}	4.3 (18)^{b}	6.1 (36.7)^{b}	3.63 (12.8)^{ab}	2.43 (5.4)^{a}	1.20 (0.9)^{b}	4.43 (19.1)^{a}
PNBR75N	1.6 (2)^{ab}	3.5 (11.7)^{ab}	1.6 (2)^{d}	4.0 (15.7)^{c}	2.72 (7.1)^{abc}	2.08 (3.81)^{ab}	0.8 (0.1)^{c}	3.39 (11.1)^{abc}
PNBR100N	1.5 (1.7)^{ab}	2.7 (7)^{ab}	0.7 (0)^{d}	3.0 (8.7)^{cd}	2.4 (5.4)^{abc}	1.04 (0.59)^{ab}	0.71 (0)^{c}	2.52(5.95)^{bcd}
PBB	2.2 (4.3)^{a}	3.1 (9.3)^{ab}	4.4 (19)^{b}	5.8 (32.7)^{b}	3.95 (15.3)^{a}	2.12 (4.01)^{ab}	1.32 (1.2)^{b}	4.57(20.53)^{a}
PBBR75N	1.9 (3)^{ab}	1.9 (3)^{ab}	0.7 (0)^{d}	2.5 (6)^{d}	2.81 (7.5)^{abc}	0.99 (0.48)^{ab}	0.71 (0)^{c}	2.9 (7.95)^{bcd}
PBBR100N	1.7 (2.7)^{ab}	2.3 (5)^{ab}	0.7 (0)^{d}	2.8 (7.7)^{d}	2.54 (6.5)^{abc}	1.03 (0.56)^{ab}	0.71 (0)^{c}	2.66 (7.04)^{bcd}
PFB	1.3 (1.3)^{ab}	2.0 (3.7)^{ab}	2.5 (6)^{c}	3.4 (11)^{cd}	2.15 (4.2)^{bc}	0.8 (0.15)^{ab}	0.85 (0.2)^{c}	2.24 (4.55)^{bcd}
PFBR75N	1.2 (1)^{b}	0.9 (0.3)^{b}	0.7 (0)^{d}	1.3 (1.3)^{e}	1.72 (3.0)^{c}	0.75 (0.06)^{ab}	0.71 (0)^{c}	1.73 (3.08)^{d}
PFBR100N	1.2 (1)^{ab}	0.7 (0)^{b}	0.7 (0)^{d}	1.2 (1)^{e}	1.94 (3.3)^{bc}	0.71 (0)^{b}	0.71 (0)^{c}	1.94 (3.29)^{cd}

Square root transformed value $(x+0.5)^{½}$, Data in the parenthesis are original data.

Table 2 Wheat yield attributes, yield, net benefit:cost (Net B:C) and irrigation water indices across the treatments

Treatment	Ear-bearing tillers (no./m)	Grains (no./spike)	1000-grain weight (g)	Grain yield (tonnes/ha)	Net B:C	Irrigation water use (mm)	Irrigation water productivity (kg/ha mm)
CT	60^{c}	52.2^{c}	40.3^{a}	4.67^{b}	1.57^{b}	300	15.5^{d}
PNB	74^{ab}	55.3^{bc}	39.8^{a}	5.05^{ab}	2.27^{a}	259	19.5^{bc}
PNBR75N	76^{ab}	58.3^{abc}	40.5^{a}	5.21^{ab}	1.96^{a}	255	20.4^{ab}
PNBR100N	77^{ab}	60.0^{abc}	40.8^{a}	5.30^{ab}	1.98^{a}	255	20.7^{ab}
PBB	74^{ab}	59.2^{abc}	39.8^{a}	5.09^{ab}	2.29^{a}	246	20.6^{ab}
PBBR75N	77^{ab}	64.1^{ab}	40.5^{a}	5.26^{ab}	1.98^{a}	238	22.0^{a}
PBBR100N	80^{a}	66.6^{a}	40.7^{a}	5.33^{a}	1.99^{a}	238	22.3^{a}
PFB	67^{bc}	53.7^{c}	40.3^{a}	5.11^{ab}	2.31^{a}	288	17.7^{c}
PFBR75N	71^{ab}	55.3^{bc}	40.4^{a}	5.28^{ab}	2.00^{a}	272	19.4^{bc}
PFBR100N	73^{ab}	56.3^{bc}	40.8^{a}	5.37^{a}	2.01^{a}	272	19.7^{bc}
Contrast analysis							
CT vs CA		-	-	4.67 vs 5.29^{**}	-	-	15.54 vs 20.77^{*}
ZT+R vs ZT		-	-	5.29 vs 5.08^{*}	-	-	20.77 vs 19.27^{*}
CA75N vs CA100N		-	-	5.25 vs 5.33^{ns}	-	-	20.60 vs 20.93^{ns}

* and ** indicate P <0.05 and P <0.001, respectively; NS: Non-significant.

variables of wheat. Therefore, it may be concluded that the CA-based permanent broad bed with residue and 100% N in the initial years and 75% N later may be adopted in the IGPs of India for better weed suppression, higher yield, profitability, and irrigation water-use efficiency.

SUMMARY

A field experiment was conducted to evaluate the impacts of a 12-year old conservation agriculture (CA)-based pigeon pea-wheat system on weeds, wheat crop, and resource use during winter (*rabi*) 2021–22. Results indicated that surface retention of residue irrespective of ZT permanent bed and N dose led to significant reduction in weed interference at 60 DAS. CA-based systems reduced weed density and dry weight considerably than CT. CA-based systems led to significantly higher wheat grain yield (by 11.6–14.9%) and net B:C (by 24.0 –28.0%) than CT, and PFBR100N and PBBR100N were slightly superior to others. PBBR100N and PBBR75N had lower irrigation water use and significantly higher irrigation water productivity than CT. Contrast analysis showed that wheat yield and water productivity were comparable between 75% N and 100% N in CA, indicating a saving of 25% N under CA.

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