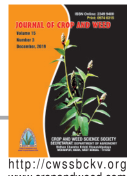
Journal of Crop and Weed, 18(1): 111-119 (2022)
ISSN- O : 2349 9400 ; P : 0974 6315



http://cwssbckv.org
www.cropandweed.com

Weed interference and wheat productivity in a conservation agriculture-based maize-wheat-mungbean system

S. GHOSH, [1*]T. K. DAS, [1]Y. S. SHIVAY, [2]K. K. BANDYOPADHYAY, [3]A. BHATIA AND [4]MD YEASIN

ICAR-Research Complex for Eastern Region, Patna 800014, Bihar; [1]Division of Agronomy; [2]Division of Agricultural Physics; [3]Centre for Environment Science and Climate Resilient Agriculture, ICAR-Indian Agricultural Research Institute; [4]Division of Statistical Genetics, ICAR-Indian Agricultural Statistics Research Institute, New Delhi 110012

Received: 08.01.2022 ; *Revised : 22.03.2022* ; *Accepted: 30.03.2022*

DOI: https://doi.org/10.22271/09746315.2022.v18.i1.1540

ABSTRACT

A field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during rabi seasons of 2018-19 and 2019-20 cropping cycles in wheat involving maize-wheat-mungbean system to assess the effects of conservation agriculture (CA) on weed interference and crop productivity. Results showed that CA-based practices with residue retention resulted in significant reduction of weed growth and led to higher yield as well as economic benefits when compared to conventional tillage (CT). The plots under permanent broad bed with residue with 100% N (PBB+R+100N) resulted in significant reduction of weed density and biomass and led to ~27% higher grain yield of wheat compared to CT. The PBB+R+100N plots also had considerably higher net returns. The CA practice involving PBB+R+100N led to considerable reduction in weed density and biomass and was found to be more productive and remunerative. However, permanent broad bed with residue with 75% N (PBB+R+75N) was found comparable in this regard and hence can be recommended for sustainable wheat production under maize-wheat-mungbean system in north-western Indo-Gangetic plains of India.

***Keywords*:** Conservation agriculture, conventional tillage, wheat, weed, yield

Conservation agriculture (CA) involving three interlinked principles, such as no or minimum mechanical soil disturbance, biomass mulch soil cover and diversified crop rotation hold opportunity for sustainable crop intensification (Kassam *et al*., 2019). Adoption of CA is progressively expanding across the tropics, sub-tropics and temperate regions of the world, in both rainfed and irrigated ecologies (Somasundaram *et al*., 2020). CA provides resource and energy efficient agricultural crop production through integrated agro-ecosystem management (Jat *et al*., 2020). Crop residue retention on the soil surface in conjunction with zero tillage (ZT) results in enhanced soil quality and overall resource enhancement (Das *et al*., 2018; Ghosh *et al*., 2019, 2021). The maize-wheat-mungbean cropping system is being promoted as an alternative to existing rice-based cropping systems of the northwestern Indo-Gangetic plains (Gathala *et al*., 2011; Parihar *et al*., 2018). Wheat (*Triticum aestivum* L.) production plays a vital role in fulfilling the food security and nutritional needs of the majority of the people in India (Nath *et al*., 2017). Recently, CA pioneered the path for increased wheat yield and resource-use efficiency (Govaerts *et al*., 2007). Kumar *et al*. (2013) reported a 33% increase in net income after three years of ZT wheat production compared to conventional tillage (CT). Weeds are the major biological constraints to the adoption of CA (Chauhan *et al*., 2012). Among different pests, weeds cause higher reduction in crop yield (Das *et al*., 2020). Conservation agriculture allows favorable conditions for both annual and perennial weed species, which results in the higher overall weed diversity under CA (Armengot *et al*., 2016). The accumulation of weeds seeds in ZT is found more near the soil surface, where they are more likely to germinate but are also exposed to greater mortality risks through weather variability and predation (Nichols *et al*., 2015). According to Susha *et al*. (2018), adopting zero tillage with residue retention in wheat resulted in 14.0% lower weed biomass and 6.9% higher wheat yields than conventional tillage.

The objective of this study is to compare the effects of conventional tillage and conservation agriculture-based crop establishment practices on weed interference in wheat and to assess the crop productivity and economic benefits of growing wheat as a component crop in a maize-wheat-mungbean system in order to choose the best tillage and crop establishment practice for its long-term intensification.

MATERIALS AND METHODS

A field experiment was conducted during the *rabi* seasons of 2018-19 and 2019-20 at Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi. The soil of the experimental site

Email: tkdas64@gmail.com

was clayey loam with a pH of 8.2, 0.60% organic C, medium available N (285 kg ha^{-1}) and P (18 kg ha^{-1}), and a high K (329 kg ha^{-1}). The experiment was laid out in a randomized complete block design with ten treatments and three replications. Wheat was sown as a component crop in a maize-wheat-mungbean system, initiated during *kharif* 2018-19. The experiment was a part of a long-term CA system, initiated in 2010. Different CA-based practices such as zero till (ZT) permanent narrow, broad and flat beds with and without retention of maize, wheat and mungbean crops residues and 75% and 100% of the recommended doses of N were compared with conventional tillage (CT) practice. The treatments were comprised of one conventional tillage practice [conventional tillage without residue with 100% N (CT)] and nine CA practices such as permanent narrow bed without residue with 100% N (PNB), permanent narrow bed with residue with 75% N (PNB+R+75N), permanent narrow bed with residue with 100% N (PNB+R+100N), permanent broad bed without residue with 100% N (PBB), permanent broad bed with residue with 75% N (PBB+R+75N), permanent broad bed with residue with 100% N (PBB+R+100N), flat bed without residue with 100% N (FB), flat bed with residue with 75% N (FB+R+75N) and flat bed residue with residue with 100% N (FB+R+100N) were followed in maize-wheat-mungbean system.

Plots for conventional tillage (CT) were prepared with a tractor-drawn disc plough followed by planking. There was no ploughing in CA-based treatments. The PNB plots had the dimension of 40 cm bed and 30 cm furrow. The PBB plots had a bed of 110 cm and a furrow of 30 cm. Maize residues were retained in CA-based residue retention plots, while plots with no residues were left undisturbed. To ensure smooth germination of wheat, the entire field was pre-irrigated. Wheat variety 'HDCSW 18' was sown during the *rabi* season with a seed rate of 100 kg ha^{-1} and row spacing of 20 cm. The sowing operation was carried out using a tractor-drawn seed cum fertilizer drill in CT. It was sown using a bed planter in CA-based PNB plots. Sowing was done with a turbo seeder in the PBB and FB plots. The fertilizer dose of 150 kg N, 26.2 kg P and 33.1 kg K ha^{-1} was applied under the 100% N treatments irrespective of CA and CT plots. In CA-based plots with 75% N, 112.5 kg N was applied. The full dose of P and K and half dose of N were applied as basal at the time of sowing. Remaining N was top-dressed in two equal splits and after first and second irrigation in wheat.

The category-wise and total weed population (density) and dry weight (biomass) were measured at 30, 60 and 90 days after sowing (DAS). An area of 0.25 m^2 was selected randomly at 3 places by a quadrat (0.5 m × 0.5 m) and weed species were counted from that area. Then the weed samples were sun-dried for three days before being placed in an oven. Then it was kept in an oven at 70^{0}C to achieve a constant weight. Before analysis of variance, data on weed density and biomass were transformed using the square-root [$\sqrt{(x+0.5)}$] method (Das, 1999). The weed density and weed biomass were expressed in numbers (no.) m^{-2} and g m^{-2}, respectively. The weed control efficiency (WCE) and weed control index (WCI) were calculated as described by Nath *et al*. (2016). The CT plot was taken as control plot.

WCE = [(Weed density in control plot-weed density in treated plot)/ weed density in control plot] × 100

WCI = [(Weed biomass (g) in control plot-weed biomass (g) in treated plot)/ weed biomass (g) in control plot] × 100

For estimating grain and straw yield, wheat crop from a net plot area of 10 m^2 was harvested and sun dried. After drying, manual threshing was carried out. Grain weight and straw weight was taken from each treatment and expressed as t ha^{-1}. The cost of cultivation under various treatments was calculated using current market prices for the various inputs used in the treatments. To determine the statistical significance of treatment effects, the data on weed interference, crop productivity and economics were analyzed using analysis of variance (ANOVA) in a randomized completed block design using R (version 4.0.5) statistical software (Anonymous, 2019). The Tukey Multiple Comparison Test was used to test for treatment differences at a 5% level of significance.

RESULTS AND DISCUSSION

Weed interference in wheat

Weed density

The major weed flora in wheat comprised of *Phalaris minor* L. among grassy weeds; and *Chenopodium album* L., *Sonchus arvensis* L., *Coronopus didymus* L., *Spergula arvensis* L., *Melilotus indica* L. and *Anagalis arvensis* L. among broad-leaved weeds. The presence of sedges in wheat was found to be very few in numbers. The dominance of grassy and broad-leaved weeds was observed to be higher in wheat among the tillage, residue and crop establishment practices. The sedge density was observed to be negligible or very few in numbers. Therefore, only the density of grasses and broad-leaved weeds has been counted periodically in wheat across the treatments. Results showed that significantly lower density of grassy weeds at 30 DAS was recorded under PBB+R+100N in both years (Fig. 1). At 60 DAS, the treatments PNB+R+100N and PBB+R+100N resulted in significant reduction of grassy weeds during 2018-19, while in 2019-20, the reduced weed density was

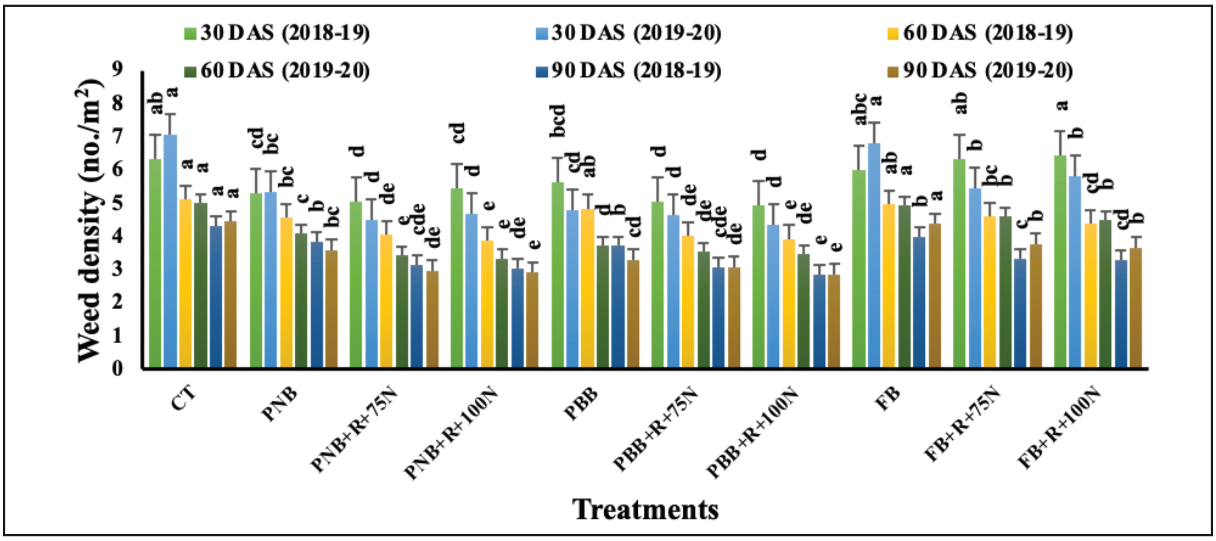


Fig. 1 : Grassy weed density in wheat across treatments at 30, 60 and 90 DAS

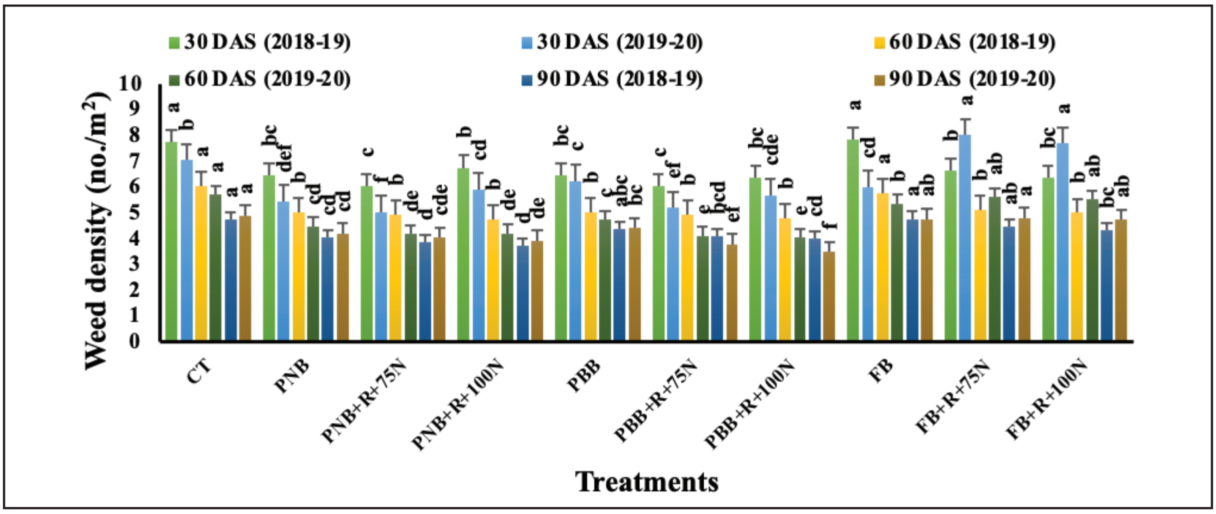


Fig. 2: Broad-leaved weed density in wheat across treatments at 30, 60 and 90 DAS

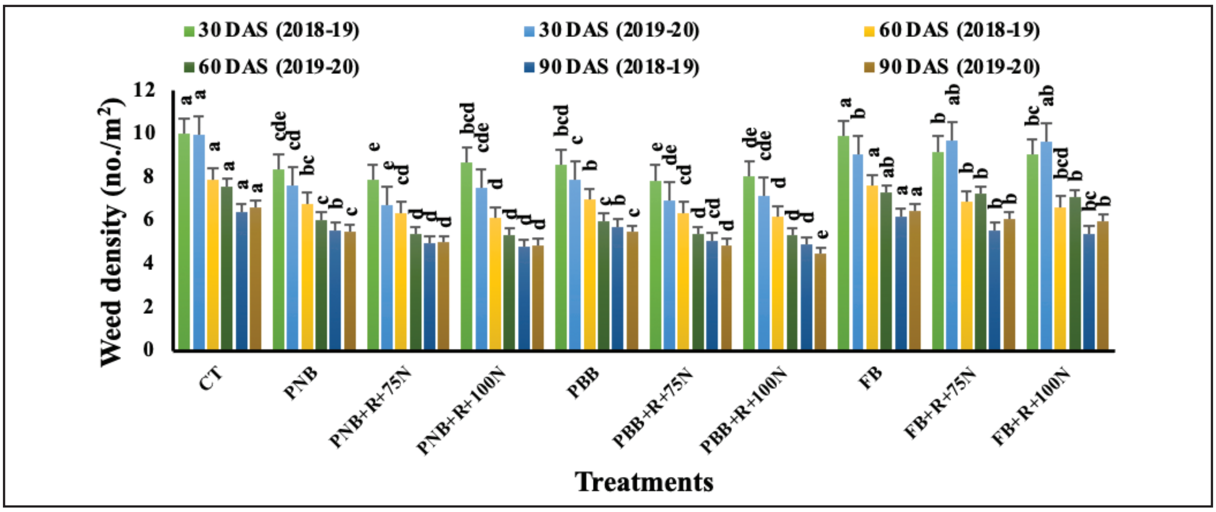


Fig. 3: Total weed density in wheat across treatments at 30, 60 and 90 DAS

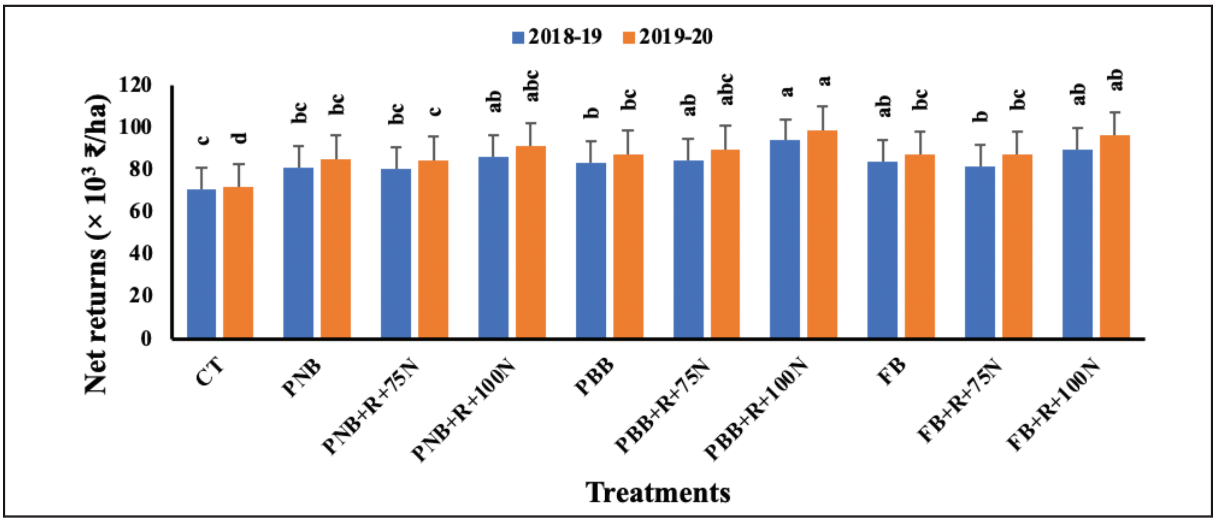


Fig. 4: Net returns in wheat across treatments

recorded under PNB+R+100N, which remained at par with PBB+R+100N, PBB+R+75N and PNB+R+75N. At 90 DAS, the treatment PBB+R+100N led to significant reduction of grassy weed density, while during 2019-20, both the treatments PBB+R+100N and PNB+R+100N significantly decreased grassy weed density. The density of grasses got substantially reduced with the progress of growth stages in wheat. The grassy weed density was observed to be significantly higher under CT practice across the growth stages in wheat except at 30 DAS during 2018-19. The CA-based narrow and broad-bed practices with residue retention irrespective of N application were found effective in reduction of grassy weeds as compared to CA-based residue removal practices as well as CT practice. The broad-leaved weed density also got significantly influenced among various tillage, residue, crop establishment and N management practices in wheat. Results indicated that the treatments PNB+R+75N and PBB+R+75N resulted in significant reduction of broad-leaved weed density at 30 DAS during 2018-19, while the treatment PNB+R+75N led to significant reduction during 2019-20 (Fig. 2). At 60 DAS, significantly lower density of broad-leaved weeds was registered under PNB+R+100N and PBB+R+100N during 2018-19 and under PBB+R+100N during 2019-20, which remained at par with PBB+R+75N, PNB+R+75N and PNB+R+100N. The treatment PNB+R+100N brought about significant reduction of broad-leaved weed density at 90 DAS during 2018-19, while the treatment PBB+R+100N registered significantly lower density of broad-leaved weeds during 2019-20. Malik *et al*. (1998) found a shift in weed species in ZT wheat fields, with a rise in density of broad-leaved weeds. Tillage, residue, crop establishment and N management practices also had significant impacts on total weed density due to significant differences observed in the density of grassy and broad-leaved weeds among the practices. Results showed that significantly lower density of total weeds at 30 DAS was obtained under PBB+R+75N during 2018-19 and under PNB+R+75N during 2019-20 (Fig. 3). These practices resulted in 22.0% and 32.3% lower density of broad-leaved weeds as compared to CT system during 2018-19 and 2019-20, respectively. The treatment PNB+R+100N resulted in significant reduction of total weed density at 60 DAS during 2018-19, while in 2019-20, the reduced weed density was recorded under PNB+R+100N and PBB+R+100N. At 90 DAS, the treatment PNB+R+100N led to significant reduction of total weed density, while during 2019-20, PBB+R+100N significantly decreased total weed density than rest of the practices. These CA-based practices reduced total weed density by 25.0% and 31.8% as compared to CT practice during 2018-19 and 2019-20, respectively. The higher reduction of total weed density was observed in the second year as compared to first year of study except for the flat bed planting practices. The total weed density was observed to be significantly higher under CT practice across the growth stages in wheat at 30, 60 and 90 DAS. The retaining of maize residues in CA-based treatments might have significantly decreased the weed infestations in wheat. Residue retention created physical barrier, as a result, weed seed germination was hindered and sunlight was prevented from reaching the soil under CA-based residue retained practices (Chauhan and Opena, 2012). The CA-based narrow and broad-bed practices with residue retention irrespective of N application were found effective in reduction of total weed density as compared to CA-based residue removal practices as well as CT practice. Similar results were reported by Baghel *et al*. (2020).

Table 1: Grassy weed biomass (g m^{-2}) across treatments in wheat

Treatments	Grassy weed biomass(g m^{-2})					
	30 DAS		60 DAS		90 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
CT	2.59 (6.24)	2.47 (5.61)	2.01 (3.56)	1.98 (3.42)	1.68 (2.33)	1.74 (2.53)
PNB	2.43 (5.40)	1.90 (3.13)	1.94 (3.28)	1.77 (2.65)	1.60 (2.06)	1.62 (2.14)
PNB+R+75N	2.21 (4.40)	1.79 (2.71)	1.80 (2.73)	1.61 (2.08)	1.54 (1.88)	1.53 (1.83)
PNB+R+100N	2.31 (4.84)	1.84 (2.88)	1.73 (2.51)	1.57 (1.97)	1.55 (1.91)	1.50 (1.75)
PBB	2.50 (5.75)	1.90 (3.11)	1.98 (3.41)	1.68 (2.32)	1.58 (2.01)	1.57 (1.98)
PBB+R+75N	2.37 (5.11)	1.80 (2.75)	1.91 (3.13)	1.58 (1.99)	1.55 (1.91)	1.51 (1.77)
PBB+R+100N	2.21 (4.37)	1.83 (2.88)	1.85 (2.94)	1.56 (1.92)	1.54 (1.87)	1.49 (1.73)
FB	2.56 (6.05)	2.24 (4.53)	2.00 (3.51)	2.00 (3.49)	1.64 (2.18)	1.69 (2.36)
FB+R+75N	2.54 (5.97)	2.14 (4.07)	1.91 (3.14)	1.92 (3.18)	1.57 (1.96)	1.62 (2.13)
FB+R+100N	2.50 (5.75)	2.19 (4.28)	1.94 (3.25)	1.90 (3.11)	1.53 (1.83)	1.60 (2.05)
SEm(±)	**0.05**	**0.08**	**0.04**	**0.02**	**0.02**	**0.02**
LSD (0.05)	**0.15**	**0.24**	**0.11**	**0.07**	**0.07**	**0.05**

Table 2: Broad-leaved weed biomass (g m^{-2}) across treatments in wheat

Treatments	Broad-leaved weed biomass(g m^{-2})					
	30 DAS		60 DAS		90 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
CT	3.56 (12.21)	3.34 (10.64)	2.72 (6.88)	2.68 (6.69)	2.07 (3.78)	2.09 (3.87)
PNB	3.27 (10.23)	2.61 (6.31)	2.53 (5.89)	2.03 (3.64)	2.01 (3.56)	1.83 (2.85)
PNB+R+75N	3.17 (9.59)	2.27 (4.65)	2.33 (4.92)	1.89 (3.09)	1.88 (3.02)	1.75 (2.57)
PNB+R+100N	3.20 (9.73)	2.51 (5.81)	2.20 (4.36)	1.94 (3.27)	1.84 (2.89)	1.72 (2.46)
PBB	3.39 (11.00)	2.80 (7.39)	2.61 (6.33)	2.17 (4.21)	1.94 (3.25)	1.85 (2.91)
PBB+R+75N	3.16 (9.51)	2.47 (5.60)	2.36 (5.06)	2.02 (3.59)	1.85 (2.94)	1.81 (2.79)
PBB+R+100N	3.27 (10.19)	2.82 (7.48)	2.32 (4.89)	1.91 (3.15)	1.84 (2.87)	1.77 (2.63)
FB	3.49 (11.67)	2.54 (5.99)	2.69 (6.76)	2.54 (5.99)	2.05 (3.69)	2.06 (3.74)
FB+R+75N	3.36 (10.77)	3.11 (9.17)	2.45 (5.49)	2.32 (4.86)	1.96 (3.35)	1.95 (3.30)
FB+R+100N	3.53 (11.97)	3.16 (9.49)	2.35 (5.01)	2.24 (4.53)	1.89 (3.08)	1.92 (3.19)
SEm(±)	**0.07**	**0.07**	**0.04**	**0.06**	**0.03**	**0.03**
LSD (0.05)	**0.22**	**0.19**	**0.11**	**0.17**	**0.09**	**0.08**

Table 3: Total weed biomass (g m^{-2}) across treatments in wheat

Treatments	Total weed biomass(g m^{-2})					
	30 DAS		60 DAS		90 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
CT	4.35 (18.45)	4.09 (16.25)	3.31 (10.44)	3.26 (10.11)	2.57 (6.11)	2.63 (6.40)
PNB	4.01 (15.63)	3.15 (9.44)	3.11 (9.18)	2.60 (6.29)	2.47 (5.62)	2.34 (4.99)
PNB+R+75N	3.80 (13.99)	2.80 (7.36)	2.85 (7.65)	2.38 (5.17)	2.32 (4.90)	2.22 (4.41)
PNB+R+100N	3.88 (14.57)	3.03 (8.69)	2.71 (6.87)	2.40 (5.24)	2.30 (4.79)	2.17 (4.21)
PBB	4.15 (16.75)	3.31 (10.49)	3.20 (9.75)	2.65 (6.53)	2.40 (5.26)	2.32 (4.88)
PBB+R+75N	3.88 (14.61)	2.97 (8.35)	2.95 (8.19)	2.47 (5.58)	2.31 (4.85)	2.25 (4.55)
PBB+R+100N	3.88 (14.56)	3.29 (10.36)	2.88 (7.82)	2.36 (5.07)	2.29 (4.74)	2.20 (4.36)
FB	4.27 (17.72)	3.31 (10.52)	3.28 (10.26)	3.16 (9.48)	2.52 (5.88)	2.57 (6.09)
FB+R+75N	4.15 (16.75)	3.71 (13.24)	3.02 (8.63)	2.92 (8.04)	2.41 (5.31)	2.44 (5.43)
FB+R+100N	4.27 (17.72)	3.78 (13.77)	2.96 (8.26)	2.85 (7.64)	2.33 (4.91)	2.39 (5.24)
SEm(±)	**0.07**	**0.08**	**0.04**	**0.05**	**0.03**	**0.02**
LSD (0.05)	**0.21**	**0.24**	**0.11**	**0.15**	**0.08**	**0.07**

Table 4: Weed control efficiency (WCE) across treatments in wheat

Treatments	Weed control efficiency (WCE)					
	30 DAS		60 DAS		90 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
CT	0	0	0	0	0	0
PNB	30.7	41.8	26.6	36.8	25.4	30.9
PNB+R+75N	38.7	54.0	35.2	50.4	40.9	43.5
PNB+R+100N	25.3	43.1	40.0	50.9	45.1	46.5
PBB	26.7	37.8	22.2	38.1	21.2	31.9
PBB+R+75N	38.7	51.3	35.2	49.6	37.7	46.5
PBB+R+100N	36.0	48.5	38.9	51.4	42.9	55.1
FB	2.7	16.0	7.1	8.2	7.1	4.7
FB+R+75N	16	5.3	24.3	9.3	25.4	15.6
FB+R+100N	18.7	6.6	29.8	12.8	29.3	18.6

Table 5: Weed control index (WCI) across treatments in wheat

Treatments	Weed control index (WCI)					
	30 DAS		60 DAS		90 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
CT	0	0	0	0	0	0
PNB	15.3	41.9	12.1	37.8	8.0	22.0
PNB+R+75N	24.2	54.7	26.7	48.9	19.8	31.1
PNB+R+100N	21.0	46.5	34.2	48.2	21.6	34.2
PBB	9.2	35.4	6.6	35.4	13.9	23.8
PBB+R+75N	20.8	48.6	21.6	44.8	20.6	28.9
PBB+R+100N	21.1	36.2	25.1	49.9	22.4	31.9
FB	4.0	35.3	1.7	6.2	3.8	4.8
FB+R+75N	9.2	18.5	17.3	20.5	13.1	15.2
FB+R+100N	4.0	15.3	20.9	24.4	19.6	18.1

Table 6: Productivity of wheat across treatments

Treatments	Wheat 2018-19			Wheat 2019-20		
	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biomass yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biomass yield ($t\ ha^{-1}$)
CT	5.08	7.36	12.45	4.89	7.55	12.43
PNB	5.37	7.65	13.03	5.31	8.11	13.42
PNB+R+75N	5.70	7.99	13.69	5.61	8.56	14.17
PNB+R+100N	5.99	8.39	14.38	5.92	8.95	14.88
PBB	5.47	7.85	13.32	5.40	8.38	13.77
PBB+R+75N	5.90	8.23	14.13	5.82	8.89	14.71
PBB+R+100N	6.38	8.61	14.98	6.29	9.18	15.48
FB	5.50	7.88	13.38	5.39	8.23	13.62
FB+R+75N	5.75	8.08	13.83	5.71	8.78	14.49
FB+R+100N	6.16	8.45	14.61	6.13	9.37	15.50
SEm(±)	**0.24**	**0.23**	**0.30**	**0.20**	**0.35**	**0.36**
LSD (0.05)	**0.71**	**0.67**	**0.88**	**0.59**	**1.03**	**1.07**

Table 7: Contrast analysis on wheat grain yield

Contrast treatments	2018-19		2019-20	
	Estimate	P value	Estimate	P value
CA *vs* CT	0.72	<0.01	0.85	<0.01
Residue (RS) *vs* No residue (NRS)	0.72	<0.01	0.75	<0.01
100N *vs* 75N	0.39	0.06	0.40	<0.05

Weed biomass

The biomass of grassy, broad-leaved and total weeds was significantly affected owing to different tillage, residue, crop establishment and N management practices. Results showed that significantly lower biomass of grassy weeds at 30 DAS was recorded under the treatments PNB+R+75N and PBB+R+100N during 2018-19 and under PNB+R+75N during 2019-20 (Table 1). Similarly at 60 DAS, the treatments PNB+R+100N and PBB+R+100N led to significant reduction of grassy weed biomass during 2018-19 and 2019-20, respectively. At 90 DAS, significantly lower grassy weed biomass was registered under the treatments FB+R+100N and PBB+R+100N during 2018-19 and 2019-20, respectively. The CT practice resulted in significantly higher biomass of grassy weeds at 30, 60 and 90 DAS except for the FB practice at 60 DAS during 2019-20. The permanent broad and narrow bed practices with residue retention significantly decreased grassy weed biomass across the growth stages in wheat. The broad-leaved weed biomass was significantly reduced under PBB+R+75N and PNB+R+75N at 30 DAS during 2018-19 and 2019-20, respectively (Table 2). At 60 DAS, the treatments PNB+R+100N and PNB+R+75N registered significantly lower biomass of broad-leaved weeds during 2018-19 and 2019-20, respectively. Similarly the treatments PBB+R+100N and PNB+R+100N led to significant reduction of broad-leaved weed biomass at 90 DAS during 2018-19 and the significantly lower broad-leaved weed biomass was observed under PNB+R+100N during 2019-20. The significant differences observed in the biomass of grassy and broad-leaved weeds among tillage, residue, crop establishment and N management practices in wheat also impacted significantly the total weed biomass. Results showed that significantly lower biomass of total weeds was obtained under the treatment PNB+R+75N at 30 DAS in both years (Table 3). This treatment resulted in reduction of weed biomass by 12.6% and 31.5% as compared to CT system during 2018-19 and 2019-20, respectively. Similarly, the treatments PNB+R+100N and PBB+R+100N brought about significant reduction of total weed biomass at 60 DAS during 2018-19 and 2019-20, respectively. These practices reduced weed biomass by 18.1% and 27.6% as compared to CT system during 2018-19 and 2019-20, respectively. Similarly at 90 DAS, significantly lower total weed biomass was registered under the treatments PBB+R+100N and PNB+R+100N during 2018-19 and 2019-20, respectively. These practices brought about 10.9% and 17.5% reduction in total weed biomass during 2018-19 and 2019-20, respectively. Susha *et al.* (2014) reported that ZT with maize residue retention reduced the density of grasses, broad-leaved and overall weeds in wheat compared to CT and ZT without residue. In the present study, significantly higher total weed biomass was recorded under CT system at 30, 60 and 90 DAS in both years. Under ZT systems, crop residue retention on the soil surface can limit weed seedling emergence, prolong the period of emergence and allow the crop to acquire an edge over weeds, reducing the need for management (Christoffoleti *et al.*, 2007; Anderson, 2010; Younesabadi *et al.*, 2013; Susha *et al.*, 2014). The significant reduction of weed density and biomass achieved under the CA-based practices resulted in higher weed control efficiency (WCE) and weed control index (WCI) than CT practice. It was observed that the treatments PNB+R+75N and PBB+R+75N recorded higher WCE at 30 DAS in 2018-19 and in 2019-20, the treatment PNB+R+75N resulted in higher WCE (Table 4). Similarly at 60 DAS, the higher WCE was obtained under the treatments PNB+R+100N and PBB+R+100N during first and second year of study. At 90 DAS, the treatments PNB+R+100N and PBB+R+100N registered higher WCE during 2018-19 and 2019-20, respectively. The treatment PNB+R+75N registered higher WCI at 30 DAS in both years (Table 5). At 60 DAS, the higher WCI was registered under the treatments PNB+R+100N and PBB+R+100N during 2018-19 and 2019-20, respectively. The treatments PBB+R+100N and PNB+R+100N recorded higher WCI at 90 DAS during 2018-19 and 2019-20, respectively. Results revealed that the CA-based practices with residue retention were found to be superior in recording higher WCE as well as WCI. Among CA-based practices, the permanent narrow and broad-bed practices with residue resulted in higher WCE and WCI as compared to flat-bed planting practice. The CA-based residue retained practices led to significant reduction of weed density and biomass in wheat owing to better crop growth and weed suppressive effects of residue retention. The treatments with 100% N and 75% N application were found at par in registering lower density and biomass of weeds in wheat. According to Zhang *et al.* (2021), aboveground weed density and species richness got reduced in wheat under ZT with crop residue retention compared to CT.

Wheat productivity and economics

The CA-based practices were found superior in increasing wheat productivity as compared to CT practice (Table 6). Among CA-based practices, the treatments with residue retention outperformed the treatments with no residue. The CA-based practices increased wheat grain yield to the tune of 5.7-25.6%, straw yield by 3.9-17% and 4.7-20.3% higher biomass yield during 2018-19, while in 2019-20, these practices resulted in 8.6-28.6% higher grain yield, 7.4-24.1% higher straw yield and 8-24.7% higher biomass yield than CT practice. Results indicated the positive effects of residue retention in improving yield in wheat cultivation. Among CA-based practices, significantly higher grain yield (6.38 t ha^{-1}), straw yield (8.61 t ha^{-1}) and biomass yield (14.98 t ha^{-1}) were registered under PBB+R+100N in 2018-19. Similarly, in 2019-20, significantly higher grain (6.29 t ha^{-1}) yield was observed under this treatment. The treatment PBB+R+100N was found to be at par with all the CA-based practices with residue retention during 2018-19 and 2019-20, except for PNB+R+75N in 2019-20. Higher grain yield in wheat under CA-based residue retained practices might be attributed to increased photosynthesis and thereby efficient translocation of photosynthates, as well as a larger sink and a stronger reproductive phase (Nath *et al*., 2015). Significantly higher straw (9.37 t ha^{-1}) and biomass (15.50 t ha^{-1}) yield was recorded under FB+R+100N during 2019-20. This treatment was found to be statistically similar with CA-based practices with residue retention. According to Nath *et al.* (2016), the carry-over effect of ZT with 5 t ha^{-1} maize residue retention + 75% N + rest N based on Green Seeker resulted in a significant increase in wheat productivity. The results of contrast analysis on wheat grain yield showed that the CA-based practices significantly increased wheat grain yield than that of CT practice (Table 7). Also the residue retention practice was found superior in comparison to residue removal practice in both years. The contrast analysis between 100% N and 75% N application was found to be non-significant during first year, while the 100% N application was observed to be superior during second year as compared to 75% N application. ZT with residue retention improves soil physical, chemical and biological properties, resulting in increased wheat yield compared to the CT system without residue retention (Hazra *et al*., 2018). Results showed that the CA-based practices resulted in significantly higher net returns over CT practice in both years (Fig. 4). Higher cost of cultivation/ land preparation and lower yield of wheat resulted in lower net returns in CT plots (Baghel *et al*., 2020). The residue retention practices were proved to be superior as compared to residue removal practices in registering higher net returns in wheat in both years. The application of 100% N had significant impacts in registering higher net returns as compared to 75% N application in both years. PBB+R+100N registered significantly higher net returns (98.82×10^3 /ha). This treatment was found at par with FB+R+100N, PNB+R+100N and PBB+R+75N.

According to the findings of the study, the CA-based permanent broad bed with residue retention with 100% N (PBB+R+100N) results in considerable reduction in total weed density and biomass with a significant increase in productivity and net returns in wheat under the maize–wheat–mungbean cropping system. However, PBB+R+75N (*i.e*., with 75% N) treatment gave comparable reduction in both weed density and biomass as well as comparable wheat yield and net returns as with the PBB+R+100N and led to a saving of 37.5 kg N ha^{-1}. Hence, PBB+R+75N may be recommended for sustainable wheat production under the maize – wheat – mungbean system in north-western Indo-Gangetic Plains of India.

ACKNOWLEDGEMENT

The financial assistance provided by ICAR-Indian Agricultural Research Institute and Department of Science and Technology (DST), Government of India is sincerely appreciated.

REFERENCES

Anderson, R.L. 2010. Weed community response to no-till in North America. *Quarantine and Protection of Plants*, **12**: 345-357.

Anonymous, 2019. R: A Language and Environment for Statistical Computing. URL. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Armengot, L., Blanco-Moreno, J.M., Bàrberi, P., Bocci, G., Carlesi, S., Aendekerk, R.,Berner, A., Celette, F., Grosse, M., Huiting, H., Kranzler, A., Luik, A., Mader, P., Peigne, J., Stoll, E., Delfosse, P., Sukkel, W., Surbock, A., Westaway, S. and Sans, F. X. 2016. Tillage as a driver of change in weed communities: a functional perspective. *Agric., Ecosys. Environ.*, **222**: 276-285.

Baghel, J.K., Das, T.K., Mukherjee, I., Nath, C.P., Bhattacharyya, R., Ghosh, S. and Raj, R. 2020. Impacts of conservation agriculture and herbicides on weeds, nematodes, herbicide residue and productivity in direct-seeded rice. *Soil Tillage Res.*, **201**: 104634.

Chauhan, B.S. and Opeña, J. 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crops Res.*, **137**: 56-69.

Chauhan, B.S., Singh, R.G. and Mahajan, G. 2012. Ecology and management of weeds under conservation agriculture: a review. *Crop Protec.*, **38**: 57-65.

Christoffoleti, P.J., De Carvalho, S.J.P., López-Ovejero, R.F., Nicolai, M., Hidalgo, E. and Da Silva, J.E. 2007. Conservation of natural resources in Brazilian agriculture: implications on weed biology and management. *Crop Protec.*, **26**(3): 383-389.

Das, T.K. 1999. Is transformation of weed data always necessary? *Ann. Agric. Res.*, **20**: 335-341.

Das, T.K., Saharawat, Y.S., Bhattacharyya, R., Sudhishri, S., Bandyopadhyay, K.K., Sharma, A. R. and Jat, M.L. 2018. Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-western Indo-Gangetic Plains. *Field Crops Res.*, **215**: 222-231.

Das, T.K., Ghosh, S., Gupta, K., Sen, S., Behera, B. and Raj, R. 2020. The weed Orobanche: species distribution, diversity, biology and management. *J. Res. Weed Sci.*, **3**(2): 162-180.

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 Sci. Soc. America J.*, **75**(5): 1851-1862.

Ghosh S., Das T.K., Shivay, Y.S., Bhatia, A., Biswas, D.R., Bandyopadhyay, K.K., Sudhishri, S., Yeasin, M., Raj, R., Sen, S. and Rathi, N. 2021. Conservation agriculture effects on weed dynamics and maize productivity in maize-wheat-greengram system in north-western Indo-Gangetic Plains of India. *Ind. J. Weed Sci.*, **53**(3): 244-251.

Ghosh, S., Das, T.K., Sharma, D. and Gupta, K. 2019. Potential of conservation agriculture for ecosystem services: A review. *Indian J. Agric. Sci.*, **89**(10): 1572-1579.

Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L. and Deckers, J. 2007. Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. *Pl. Soil*, **291**(1): 39-54.

Hazra, K.K., Ghosh, P.K., Venkatesh, M.S., Nath, C.P., Kumar, N., Singh, M. and Nadarajan, N. 2018. Improving soil organic carbon pools through inclusion of summer mungbean in cereal-cereal cropping systems in Indo-Gangetic plain. *Arch. Agron. Soil Sci.*, **64**(12): 1690-1704.

Jat, H.S., Choudhary, K.M., Nandal, D.P., Yadav, A.K., Poonia, T., Singh, Y., Sharma, P.C. and Jat, M.L. 2020. Conservation agriculture-based sustainable intensification of cereal systems leads to energy conservation, higher productivity and farm profitability. *Environ. Management*, **65**(6): 774-786.

Kassam, A., Friedrich, T. and Derpsch, R. 2019. Global spread of conservation agriculture. *Int. J. Environ. Studies*, **76**(1): 29-51.

Kumar, V., Saharawat, Y.S., Gathala, M.K., Jat, A.S., 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-Gangetic Plains. *Field Crops Res.*, **142**: 1-8.

Malik, R.K., Gill, G. and Hobbs, P.R. 1998. Herbicide Resistance-A Major Issue for Sustaining Wheat Productivity in Rice–Wheat Cropping Systems in the Indo Gangetic Plains. Rice–Wheat Consortium Paper Series 3. RWC, New Delhi, India.

Nath, C.P., Das, T.K. and Rana, K.S. 2016. Effects of herbicides and tillage practices on weeds in summer mungbean (*Vigna radiata*) in wheat (*Triticum aestivum*)-mungbean cropping sequence. *Ind. J. Agric. Sci.*, **86**(7): 860-864.

Nath, C.P., Das, T.K., Rana, K.S., Bhattacharyya, R., Pathak, H., Paul, S. and Singh, S.B. 2017. Greenhouse gases emission, soil organic carbon and wheat yield as affected by tillage systems and nitrogen management practices. *Arch. Agron. Soil Sci.*, **63**(12): 1644-1660.

Nath, C.P., Das, T.K., Rana, K.S., Pathak, H., Bhattacharyya, R., Paul, S., Singh, S.B. and Meena, M.C. 2015. Weed-management and wheat productivity in a conservation agriculture-based maize (*Zea mays*)-wheat (*Triticum aestivum*)-mungbean (*Vigna radiata*) system in north-western Indo-Gangetic plains of India. *Ind. J. Agron.*, **60**(4): 554-563.

Nichols, V., Verhulst, N., Cox, R. and Govaerts, B. 2015. Weed dynamics and conservation agriculture principles: A review. *Field Crops Res.*, **183**: 56-68.

Parihar, C.M., Jat, S.L., Singh, A.K., Kumar, B., Rathore, N.S., Jat, M.L. and Kuri, B.R. 2018. Energy auditing of long-term conservation agriculture based irrigated intensive maize systems in semi-arid tropics of India. *Energy*, **142**: 289-302.

Somasundaram, J., Sinha, N.K., Dalal, R.C., Lal, R., Mohanty, M., Naorem, A.K., Hati, K.M., Chaudhary, R.S., Biswas, A.K., Patra, A.K. and Chaudhari, S.K., 2020. No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. *Critical Rev. Plant Sci.*, **39**(3): 236-279.

Susha, V.S., Das, T.K., Nath, C.P., Pandey, R., Paul, S. and Ghosh, S. 2018. Impacts of tillage and herbicide mixture on weed interference, agronomic productivity and profitability of a maize–wheat system in the North-western Indo-Gangetic Plains. *Field Crops Res.*, **219**: 180-191.

Susha, V.S., Das, T.K., Sharma, A.R. and Nath, C.P. 2014. Carry-over effect of weed management practices of maize (*Zea mays*) on weed dynamics and productivity of succeeding zero and conventional till wheat (Triticum aestivum). *Indian J. Agron.*, **59**(1): 41-47.

Younesabadi, M., Das, T.K. and Pandey, R. 2013. Effect of herbicide tank-mixes on weed control, yield and physiological parameters of soybean (Glycine max) under tilled and no-tilled conditions. *Indian J. Pl. Physiol.*, **18**(3): 290-294.

Zhang, J. and Wu, L.F. 2021. Impact of tillage and crop residue management on the weed community and wheat yield in a wheat–maize double cropping System. *Agriculture*, **11**(3): 265.