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Conservation agriculture effects on weed dynamics and maize productivity in maize- wheat- greengram system in north-western Indo-Gangetic Plains of India

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ABSTRACT

Conservation agriculture (CA) can promote sustainable crop intensification. However, weeds are the major constraints under CA, in the initial years. Nitrogen (N) management under CA is also crucial. A field experiment was undertaken to study the effect of conventional tillage (CT) and CA with and without residue using 75 and 100% recommended N dose on weed dynamics and crop productivity during 2018-19 and 2019-20 in maize (*Zea mays* L.) under maize - wheat (*Triticum aestivum* L.) - greengram (*Vigna radiata* (L.) Wilczek) cropping system at ICAR-Indian Agricultural Research Institute, New Delhi. Nine CA-based treatments and one conventional tillage were laid out in a randomized complete block design with three replications. CA-based zero till (ZT) bed planting systems with residue retention resulted in significant reductions in total weed density and biomass compared to CT. Permanent broad bed with residue using 75% N resulted in 34% lesser weed density than CT. Among the CA-based treatments, the permanent broad bed with residue using 100% N resulted in ~22% higher maize grain yield than CT (5.72 t/ha) with 36% higher net returns than CT. However, the permanent broad bed with residue using 75% N was found comparable in this regard and may be recommended for sustainable maize production under the maize-wheat-greengram system in north-western Indo Gangetic Plains of India.

INTRODUCTION

Conservation agriculture (CA) is a "concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO, 2001). CA is characterized by three inter-linked principles, namely continuous no or minimal mechanical soil disturbance, maintenance of a permanent biomass mulch cover on soil surface and diversified crop rotations including a legume (Ladha *et al.* 2016, Kassam *et al.* 2019). CA is being promoted and adopted for sustainable crop intensification (Kassam *et al.* 2009, FAO 2011 Chakraborty *et al.* 2017). Maize has wider adaptability and compatibility under diverse soil and climatic situations and can be a potential substitute of rice in areas with scarcity of labour and water (Gathala *et al.* 2013, Susha *et al.* 2014, Das *et al.* 2018). Several researchers have identified CA-based sustainable intensification of maize-wheat-greengram system, which can enhance crop productivity, profitability, water use efficiency, energy use efficiency, weed control efficiency and lead to accumulation of more organic carbon in soil with high sequestration potential (Saad *et al.* 2015, Nath *et al.* 2017, Das *et al.* 2018, Ghosh *et al.* 2019, Jat *et al.* 2020). However, weeds are major constraint for the success of CA. The absence of tillage in CA makes weed management a greater challenge than conventional agriculture (Chauhan *et al.* 2012). In addition, with frequent rainfall in rainy (*Kharif*) season, weeds continue to emerge in repeated flushes and pose severe competitive interference with maize. Weeds are ubiquitous, having a wide range of ecological amplitude that determines their adaptability

(Das 2008). Certain weed species germinate and grow more profusely than others under continuous zero till (ZT) system. As a result, weed shift occurs (Erenstein and Laxmi 2008, Nichols *et al*. 2015) with the change from conventional till (CT) to ZT system which can affect weed dynamics including weed seed distribution and abundance in soil seed bank (Mulugeta and Stoltenberg 1997, Nath *et al*. 2015). Weeds pose tremendous challenge for successful crop production and their management usually costs higher than that of other agro-practices (Das *et al*. 2020). However, weed problems are likely to reduce in course of time, if the three principles of CA are combinedly used (Nichols *et al*. 2015). Thus, the objective of this study was to quantify the weed dynamics and productivity and profitability of maize cultivation under CA-based maize-wheat-greengram system.

MATERIALS AND METHODS

A field experiment was carried out during the rainy (*Kharif*) seasons of 2018-19 and 2019-20 (*i.e.* in the 9th and 10th year of a long-term CA experiment) at Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi. Ten treatments with three replications were laid out in a randomized complete block design. The experiment was a part of a long-term CA system, initiated in 2010. In this system, different CA-based practices such as zero till (ZT) permanent narrow, broad and flat beds with and without retention of maize, wheat and greengram crops residues) and 75% and 100% of the recommended dose of N were compared with CT practice. The treatments comprised of conventional tillage [*i.e*. conventional tillage without residue but with 100% N (CT)], and nine CA practices: ZT with permanent narrow bed (PNB), broad bed (PBB) and flat bed (FB) without residue but with 100% N (3 treatments: PNB+100N, PBB+100N and FB+ 100N); PNB, PBB and FB with residue (R) and 75% N (three treatments; PNB+R+75N, PBB+R+75N, FB+R+75N); and PNB, PBB and FB with R and 100% N (three treatments: PNB+R+100N, PBB+R+100N and FB+R+100N). CT plots were prepared using tractor-drawn disc plough followed by planking.

In CA-based treatments (PNB, PBB and FB with or without residue), no ploughing was done. The PNB plots had the dimension of 40 cm bed and 30 cm furrow. The PBB plots had 110 cm bed and 30 cm furrow. In CA-based residue retention plots, residues of wheat grown in previous season were applied and plots with no residues were left undisturbed. Soil of the experimental site was clayey loam, pH (8.2), organic C (0.60%), medium in available N (285 kg/ha) and P (18 kg/ha) and high in K (329 kg/ha). A pre-sowing irrigation was given to entire field to ensure smooth germination of maize. Maize variety 'PMH 1' was sown during rainy (*Kharif*) season with a seed rate of 20 kg/ha at 70 cm row spacing. In CT, maize was sown using a tractor-drawn seed cum fertilizer drill. In CA-based PNB plots, it was sown using a bed planter. In PBB and FB plots, the sowing was done using turbo seeder. The recommended dose 150 kg N, 26 kg P and 33 kg K was applied to maize crop 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 50% amount of the 75% and 100% N (as applicable to the treatment) and full dose of P and K were applied as basal. Remaining N was applied in 2 equal splits at 30 and 60 days after sowing (DAS) of maize. Nitrogen was applied using urea and diammonium phosphate (DAP), P was applied using DAP, and K using muriate of potash (MOP).

Species-wise, category-wise and total weed population (density) and dry weight (biomass) were recorded at 30 DAS. An area of 0.25 m^2 surrounding a maize crop row was selected randomly at 3 spots by a quadrat (0.5 × 0.5 m) and weed species were counted from that area. Species-wise collected weed samples were sun-dried for three days and kept in an oven at 70^{0}C till constant weight obtained. Data on weed density and biomass were transformed through square-root [$\sqrt{x+0.5}$] method before analysis of variance (Das 1999). The total weed density and biomass were computed as the summation of original values of grasses, broad-leaved weeds and sedges and then these values were transformed through square root method. Maize cobs of the net plot area were separated from plants, sun-dried for 5 days and cob yield was recorded. Maize grains were separated from the cobs and dried to about 12% moisture in an oven for recording cob grain yield. The cost of cultivation under various treatments was estimated on the basis of prevailing market prices of various inputs used in the treatments. For gross returns, minimum support price of maize grains declared by the Government of India during 2018 and 2019, and the market price of maize stover were considered. The net benefit: cost of various treatments was estimated as the ratio of net returns to cost of cultivation. The two-year pooled data on weed density, weed biomass, crop productivity, net returns, net benefit: cost and nutrient uptake were subjected to analysis of variance (ANOVA) in a randomized completed block design using R (version 4.0.5) statistical software to determine the statistical significance of treatment effects (R Core Team, 2013). The treatment differences were tested with the help of Tukey Multiple Comparison Test at 5% level of significance.

RESULTS AND DISCUSSION

Weed density and biomass

Weed flora in maize comprised of *Setaria viridis* (L.) P.Beauv., *Leptochloa chinensis* (L.) Nees, *Cynodon dactylon* (L.) Pers., *Dinebra retroflexa (Vahl) Panz.*, *Dactyloctenium aegyptium* (L.) Willd. among grasses; *Commelina benghalensis* L., *Digera arvensis* Forssk., *Euphorbia hirta* L., *Euphorbia microphylla* Lam., *Trianthema portulacastrum* L., *Amaranthus viridis* L. among broad-leaved weeds and *Cyperus rotundus* L. and *Cyperus esculentus* L. among sedges. Among them, the most dominant were *S. viridis*, *C. benghalensis* and *C. esculentus*. Differences in weed density and biomass of grassy, broad-leaved and sedge weeds at 30 DAS were significant due to differential crop establishment, residue and N management practices (**Table 1**). Among different weed flora, sedges density was higher in CT. The CT treatment reduced grassy weeds, but was not effective in reducing total weed density and biomass. Among CA-based treatments, the residue retention has caused significant reduction in weed density compared to no residue treatments. Permanent narrow bed with residue retention with 75% N caused significant reduction in both *S. viridis* and *C. benghalensis*, whereas *C. esculentus* density and biomass was significantly reduced under permanent broad bed with residue retention with 100% N (**Figure 1** and **2**). The prevalence of grassy weeds was significantly lower under PNB+R+75N. Both the PBB+R+75N and PNB+R+100N treatments were found to be superior in controlling broad-leaved weed density. Similarly, sedges were significantly reduced under FB+R+75N and PBB+R+100N. Grassy weeds and sedges were higher in second year than first year, whereas broad-leaved weed population was significantly lower in second year. The CA-based practices also resulted in significant reduction in total weed density and biomass. The treatments PBB+R+75N and PNB+R+75N were superior in causing significant reduction in total weed density and biomass. PNB+R+75N and PBB+R+75N recorded 28% and 34% lesser weed density, respectively than the CT practice due to emergence of greater number of grasses and sedges than broad-leaved weeds. Higher infestation of these weeds in CT might be due to soil inversion caused by tillage, greater aeration and periodical irrigation application (Baghel *et al*. 2020). CA-based treatments with residue retention led to reduce weed interference due to the smothering effect on weeds. In CA, weed interference and N immobilization can be reduced by adaptive N fertilizer application and weed management (Oyeogbe *et al*. 2018). CA practices helped prevent proliferation of weeds and minimized negative impact of weeds on crop productivity. Soil inversion with CT led to increased weed pressure. Crop residue retention with ZT could delay as well as suppress weed germination and emergence. It could be a multi-tactic approach for sustainable weed management in crop rotations, reducing the need for herbicides application (Christoffoleti *et al*. 2007, Susha *et al*. 2014, Nath *et al*. 2016).

Maize yield and economics

Maize yield differed significantly amongst the tested treatments in both years (**Table 2**). The CA-based permanent broad bed with residue retention with 100% N (PBB+R+100N) recorded significantly higher grain as well as stover yield of maize under maize-wheat-greengram system. It registered 24% and 20% higher grain yield than CT practice, in 2018 and 2019, respectively. The combination of broad bed with residues using 75% or 100% N (PBB+R+75N or

Table 1. Category-wise weed density and weed biomass as influenced by treatments at 30 DAS in maize (pooled of two years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)			
	Grassy weeds	Broad-leaved weeds	Sedges	Total weeds	Grassy weeds	Broad-leaved weeds	Sedges	Total weeds
CT	6.2^g	4.7^b	17.4^a	19.3^a	5.82^h	3.33^b	11.61^a	13.59^a
PNB	5.9^{gh}	5.4^a	12.9^b	15.7^c	5.59^h	3.64^a	7.84^b	10.61^c
PNB+R+75N	5.8^h	4.7^b	11.6^c	14.0^d	6.35^g	2.38^e	5.67^e	8.87^f
PNB+R+100N	8.4^e	3.1^d	9.5^d	13.0^e	7.30^e	1.87^g	5.75^e	9.44^e
PBB	10.5^b	5.0^a	12.1^c	17.2^b	9.31^a	2.88^c	6.32^d	11.60^b
PBB+R+75N	9.1^d	2.8^e	8.3^e	12.7^e	7.87^d	1.80^g	5.00^f	9.47^e
PBB+R+100N	11.5^a	4.0^c	6.4^f	13.9^d	9.00^b	2.60^d	3.43^h	10.00^d
FB	8.1^f	3.7^c	8.3^e	12.7^e	6.81^f	2.11^f	4.55^g	8.65^f
FB+R+75N	9.7^c	3.8^c	8.1^e	13.2^e	8.34^c	2.34^e	4.91^f	9.97^d
FB+R+100N	9.0^d	3.9^c	11.6^c	15.6^c	7.91^d	2.33^e	6.61^c	10.72^c

Refer materials and methods for treatment details

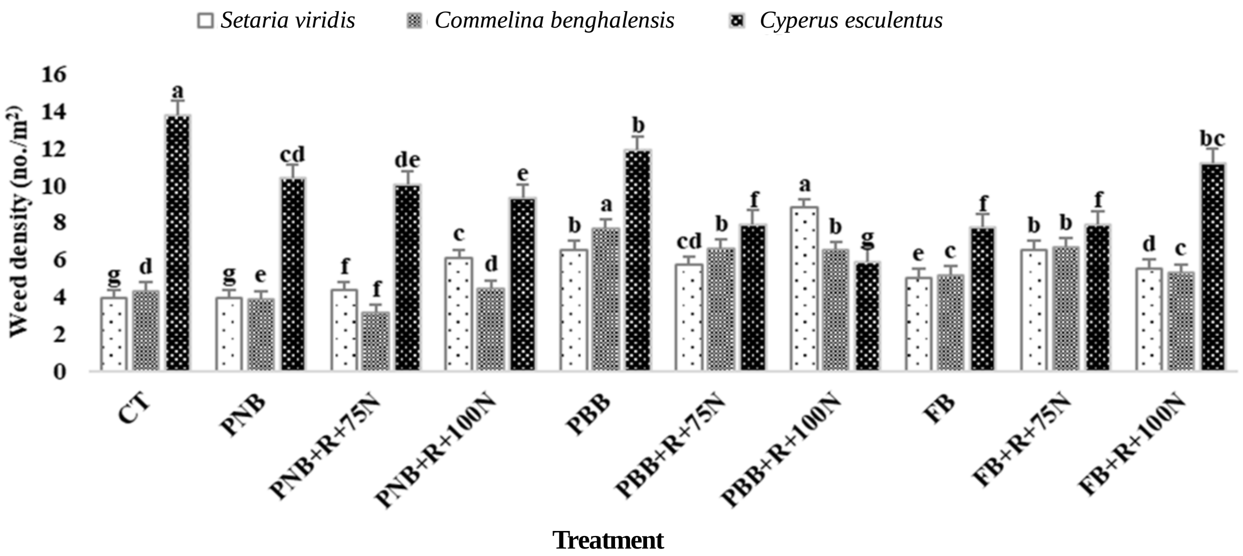

Figure 1. The density (no./m^2) of *Setaria viridis, Commelina benghalensis* and *Cyperus esculentus* (dominant weeds) as influenced by treatments at 30 DAS in maize (pooled of two years)

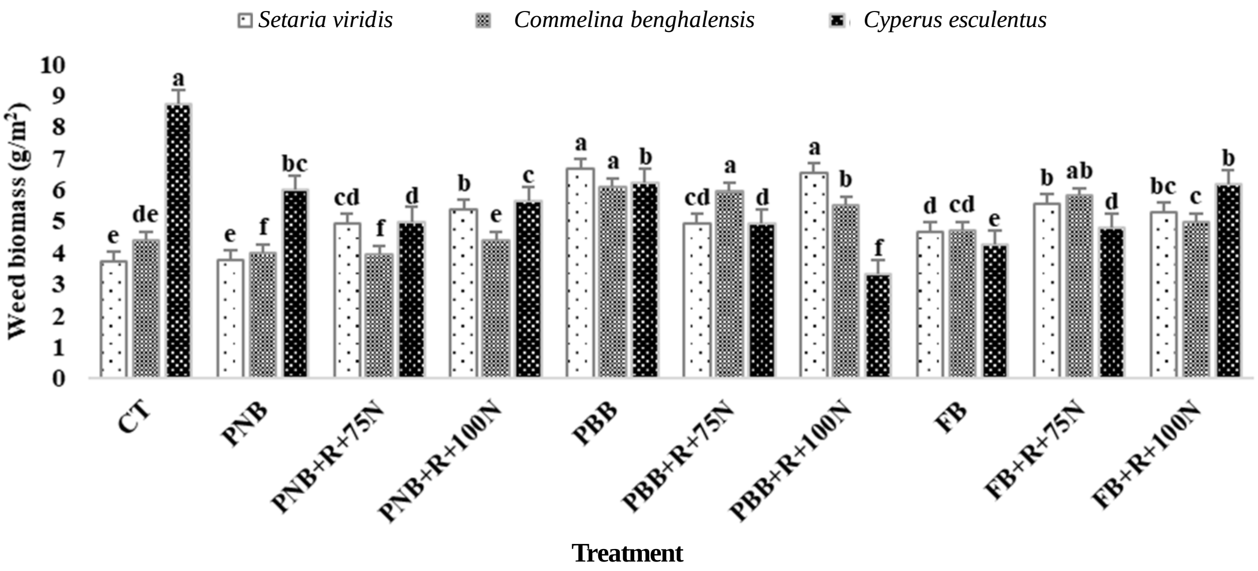

Figure 2. The biomass (g/m^2) of *Setaria viridis, Commelina benghalensis* and *Cyperus esculentus* (dominant weeds) as influenced by treatments at 30 DAS in maize (pooled of two years)

PBB+R+100N) gave comparable yield of maize. Weed interference and crop yield are negatively correlated (Das and Yaduraju 2011). A considerable reduction in weed density and biomass due to greater suppressive effect of CA-based permanent broad bed with residue retention (PBB+R) led to higher grain yield of maize compared to CT and other ZT bed planting practices without residue. Besides, better weed management, the triple zero tillage systems involving retention of residues of maize, wheat and greengram might have led to better soil aggregation (Bhattacharyya *et al.* 2013), higher soil moisture retention capacity (Nath *et al.* 2015) and more C and N sequestration (Das *et al.* 2018) leading to higher yield of maize over the years in this CA-based practice. The ZT broad bed planting with residue retention helped increase in yield attributing characters of maize such as grains/cob and seed index, which resulted in higher grain as well as biological yield of maize (Saad *et al.* 2015). Retention of greengram residue along with wheat residue might have increased soil N, which favored better growth and development in maize in CA-based practices. The CA-based practices with residue retention registered 16-22% higher grain yield and 12-17% higher stover yield of maize than CT practice, indicating the superiority of CA practices in favorably influencing the better photosynthates accumulation, growth and development of maize crop than CT. Grain yield of maize was also influenced by the growing season. The grain and stover yields were found higher in first year than second year. The CA-based practices without residue retention gave lower grain and stover yields than residue retained plots indicating the need for residue retention for better weed management and higher maize yield. The PBB+R+100N treatment through better weed management and higher maize yield could compensate the cost of residue addition and resulted in higher net returns and net benefit: cost than CT and other CA practices in both years. This treatment resulted in 35.8% higher net returns than CT. The next best treatment was FB+R+100 N in terms of net returns as well as net benefit: cost. The PBB+R+75N was statistically at par with PBB+R+100N in terms of net returns due to savings in N application and higher grain and stover yield. CT practice had lower net benefit: cost due to higher cost involved in land preparation, manual weeding and lower grain and stover yield (Chander *et al*. 2013). The cost incurred by CT was observed to be 5.0%, 6.4% and 10.6% higher than permanent broad-bed planting+R+100N, permanent broad-bed planting+R +75N, and permanent broad- bed planting without residue, respectively. The ZT bed planting practices with or without residues were comparable in terms of net benefit: cost because of savings in cost incurred due to residue addition (**Table 2**).

Contrast analysis for weed biomass and maize grain yield

The impacts of individual treatments tested in this study were also assessed through contrast analysis (**Table 3**). The contrast analysis showed that CA was not found effective in reducing biomass of *S. viridis*. It resulted in significant reduction in biomass of *C. benghalensis* in second year than first year and significantly reduced *C. esculentus* biomass during both the years. In case of reduction in total weed

Table 2. Grain, stover and total biomass yields of maize, net returns and net benefit: cost as affected by different treatments

Treatment	Grain yield (t/ha)			Stover yield (t/ha)			Total biomass yield (t/ha)			Net returns (× 10³ ₹/ha)			Net B:C
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	
CT	5.80^{d}	5.63^{d}	5.72^{e}	8.62^{d}	9.08^{c}	8.85^{c}	14.42^{e}	14.71^{d}	14.57^{f}	75.96^{d}	73.87^{c}	74.92^{f}	1.80^{c}
PNB	6.46^{c}	6.09^{cd}	6.28^{d}	9.27^{cd}	9.64^{abc}	9.46^{b}	15.73^{d}	15.74^{c}	15.74^{e}	92.54^{c}	87.15^{b}	89.85^{e}	2.40^{b}
PNB+R+75N	6.65^{abc}	6.31^{abc}	6.48^{bcd}	9.78^{abc}	9.90^{ab}	9.84^{ab}	16.43^{cd}	16.21^{abc}	16.32^{cd}	95.30^{bc}	89.94^{ab}	92.62^{cde}	2.38^{b}
PNB+R+100N	6.83^{abc}	6.48^{abc}	6.66^{abc}	9.70^{abc}	10.12^{ab}	9.91^{ab}	16.53^{cd}	16.60^{ab}	16.57^{c}	97.69^{abc}	92.91^{ab}	95.30^{bcde}	2.41^{b}
PBB	6.61^{bc}	6.18^{bc}	6.40^{bcd}	9.36^{cd}	9.79^{ab}	9.57^{b}	15.97^{cd}	15.97^{bc}	15.97^{de}	95.21^{bc}	88.97^{ab}	92.10^{cde}	2.46^{ab}
PBB+R+75N	6.95^{abc}	6.49^{abc}	6.72^{ab}	9.61^{abcd}	10.11^{ab}	9.86^{ab}	16.57^{cd}	16.61^{ab}	16.59^{c}	100.07^{abc}	93.65^{ab}	96.86^{abc}	2.49^{ab}
PBB+R+100N	7.21^{a}	6.75^{a}	6.98^{a}	10.58^{a}	10.17^{a}	10.37^{a}	17.79^{a}	16.91^{a}	17.35^{a}	105.80^{a}	97.70^{a}	101.75^{a}	2.58^{a}
FB	6.55^{bc}	6.10^{cd}	6.32^{cd}	9.47^{bcd}	9.54^{bc}	9.50^{b}	16.02^{cd}	15.63^{c}	15.82^{de}	94.36^{c}	87.00^{b}	90.68^{de}	2.42^{b}
FB+R+75N	6.97^{abc}	6.41^{abc}	6.69^{abc}	9.83^{abc}	10.07^{ab}	9.95^{ab}	16.80^{bc}	16.48^{ab}	16.64^{bc}	100.74^{abc}	92.10^{ab}	96.42^{abcd}	2.48^{ab}
FB+R+100N	7.11^{ab}	6.62^{ab}	6.86^{a}	10.42^{ab}	10.14^{ab}	10.28^{a}	17.53^{ab}	16.75^{a}	17.14^{ab}	103.78^{ab}	95.36^{ab}	99.57^{ab}	2.52^{ab}

Refer the materials and methods for details of the treatments

Table 3. Contrast analysis on weed biomass and maize grain yield over the years

Parameter		Contrast treatment	2018		2019	
			Estimate	p-value	Estimate	p-value
Weed biomass	*Setaria viridis*	CA *vs* CT	1.33	<0.01	1.86	<0.01
		Residue *vs* no residue	-0.14	<0.01	0.96	<0.01
		75% N *vs* 100% N	-0.33	<0.01	-0.84	<0.01
	Commelina benghalensis	CA *vs* CT	1.78	<0.01	-0.49	<0.01
		Residue *vs* no residue	0.46	<0.01	-0.15	0.88
		75% N *vs* 100% N	-0.56	<0.01	1.12	<0.01
	Cyperus esculentus	CA *vs* CT	-3.69	<0.01	-3.44	<0.01
		Residue *vs* no residue	0.58	<0.01	-1.61	<0.01
		75% N *vs* 100% N	0.03	0.86	-0.34	0.09
	Total weed	CA *vs* CT	-2.67	<0.01	-4.65	<0.01
		Residue *vs* no residue	-0.63	<0.01	-0.46	<0.01
		75% N *vs* 100% N	-0.90	<0.01	-0.33	<0.01
Maize grain yield		CA *vs* CT	1.02	<0.01	0.75	<0.01
		Residue *vs* no residue	0.41	<0.01	0.39	<0.01
		75% N *vs* 100% N	-0.19	0.25	-0.21	0.15

biomass, CA showed superiority over CT practice. CA recorded higher grain yield of maize compared to CT during both the years of the study. Contrast analysis revealed that residue retention was superior to no residue towards reducing weed biomass. Residue-retained treatments significantly reduced biomass of *S. viridis* during first year and that of *C. benghalensis* and *C. esculentus* in second year. Residue retention caused significant reduction in total weed biomass compared to no-residue treatments during both the years. These treatments recorded significantly higher maize grain yield than no-residue treatments. The 100% N application resulted in more weed proliferation compared to treatments with 75% N. The treatments with 75% N significantly reduced *S. viridis* during the both years and *C. benghalensis*. The contrast between 75% N and 100% N were found to be non-significant in reducing infestation of *C. esculentus* during both the years. Treatments with 75% N significantly reduced total weed growth compared to treatments with 100% N. The residue retention was proved superior to no-residue treatments in enhancing maize grain yield. The differences between 75% N and 100% N were found to be non-significant during both the years, indicating that these were similar with each other in recording maize grain yield. Thus, CA with residue retention and with 75% N could be used to reduce weed growth and enhance grain yield of maize.

Nutrient uptake by maize

The tillage/bed planting, residue, and N management significantly influenced N, P and K uptake by crop. The highest nutrient (N, P and K) uptake in maize was observed under PBB+R+100 N and the least was in CT during both the years (**Figures 3, 4, 5, 6, 7, 8, 9, 10** and **11**). Residue retention, better weed management, better root growth and proliferation and improved soil physical, chemical and biological properties under zero tillage enhanced nutrient uptake by both grain and stover. The significantly higher N uptake was recorded with

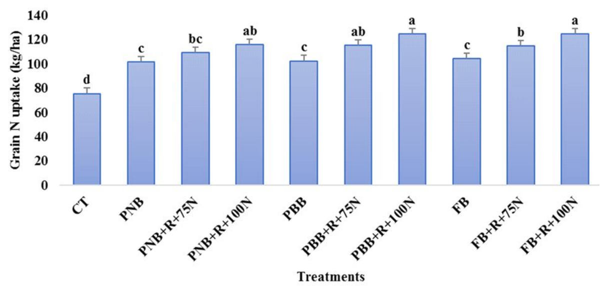

Figure 3. N uptake by maize grain as affected by treatments (pooled of two years)

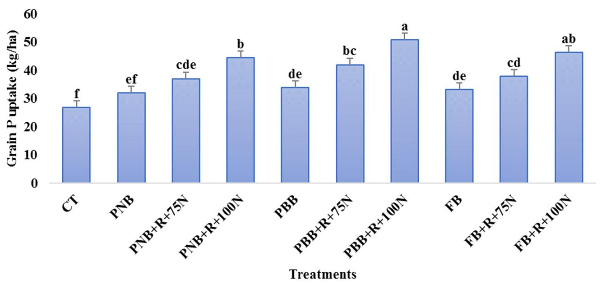

Figure 4. P uptake by maize grain as affected by treatments (pooled of two years)

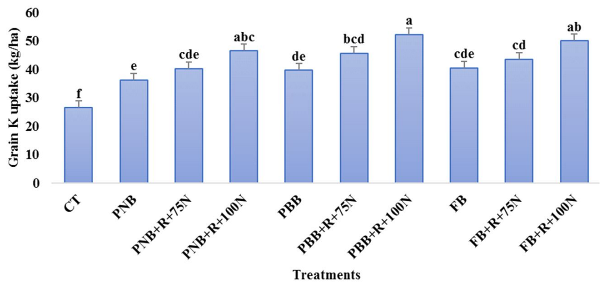

Figure 5. K uptake by maize grain as affected by treatments (pooled of two years)

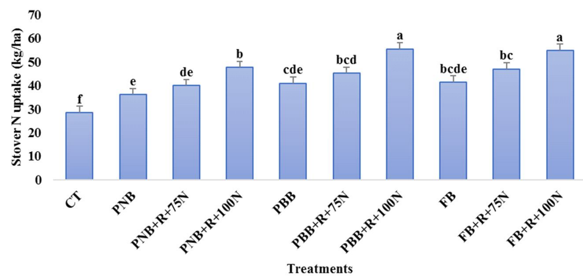

Figure 6. N uptake by maize stover as affected by treatments (pooled of two years)

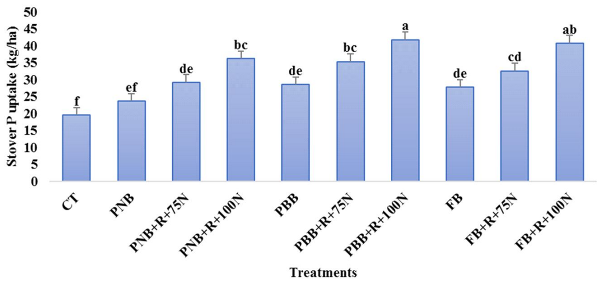

Figure 7. P uptake by maize stover as affected by treatments (pooled of two years)

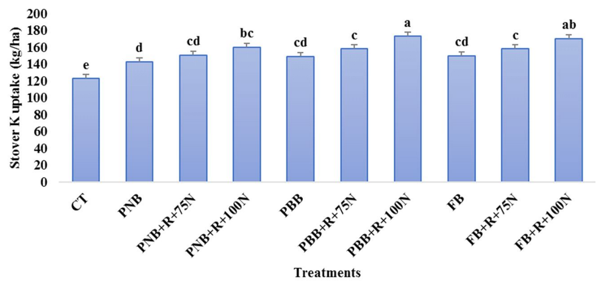

Figure 8. K uptake by maize stover as affected by treatments (pooled of two years)

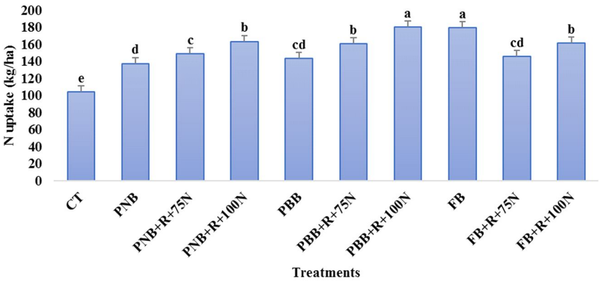

Figure 9. Total N uptake by maize as affected by treatments (pooled of two years)

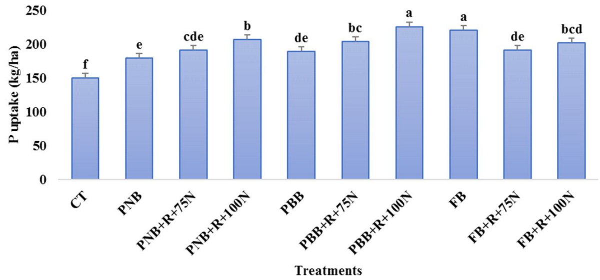

Figure 10. Total P uptake by maize as affected by treatments (pooled of two years)

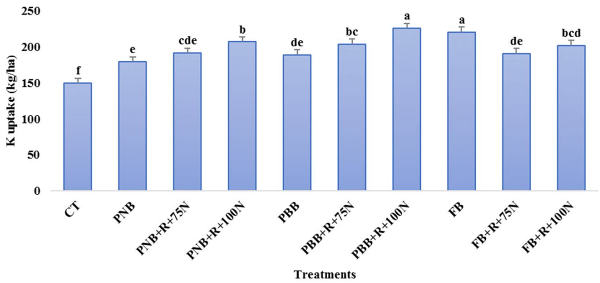

Figure 11. Total K uptake by maize as affected by treatments (pooled of two years)

FB+R+100N in the first year and PBB+R+100N in the second year. The later recorded higher P and K uptake during both the years. The treatment PBB+R+100 N caused mean of grain N uptake of 124.62 kg/ha, grain P uptake of 50.7 kg/ha and grain K uptake of 52.32 kg/ha. Similarly, this treatment registered mean stover N uptake of 55.52 kg/ha, stover P uptake of 41.82 kg/ha and stover K uptake of 173.34 kg/ha. The PBB+R+100N recorded total N uptake of 180.14 kg/ha, P uptake of 92.52 kg/ha and K uptake of 225.66 kg/ha. The CA-based treatments with residue retention caused considerably higher nutrient uptake than those without residue retention. The reduction in nutrient uptake by maize in CT practice was due to emergence of more grassy weeds and sedges, intensive tillage operations, nutrient losses, less soil water retention and impaired soil physical, chemical and biological properties (Nath *et al.* 2015, Singh *et al.* 2016, Das *et al.* 2018).

The study indicates that the CA-based permanent broad bed with residue retention and 100% N (PBB+R+100N) results in considerable reduction in total weed density and biomass with a significant increase in productivity, nutrients (N, P and K) uptake and net returns in maize under the maize–wheat–greengram triple cropping system. However, PBB+R+75N (*i.e.*, with 75% N) treatment gave comparable maize yield, net returns and net benefit: cost with the PBB+R+100N (i.e. with 100% N) and led to a saving of 37.5 kg N/ha, which may likely reduce greenhouse gas (~N_2O) emission from maize field. Hence, PBB+R+75N may be adopted for maize under the maize – wheat – greengram system in north-western Indo-Gangetic Plains of India.

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