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RESEARCH NOTE

Tillage, residue, and nitrogen management effects on weed interference, wheat growth, yield and nutrient uptake under conservation agriculture-based pigeonpea-wheat system

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ABSTRACT

A field experiment laid out in a randomized complete block design with three replications was undertaken to evaluate the impacts of 12-year old conservation agriculture (CA)-based pigeonpea-wheat system on weeds and wheat during winter (*Rabi*) 2021-22. There were 10 treatments comprising of conventional till flatbed (CT), zero till (ZT) permanent narrow bed (PNB), broad bed (PBB), and flatbed (PFB) with (PNBR, PBBR, PFBR) and without residue (R). Residue retention treatments (PNBR, PBBR, PFBR) had 75% and 100% of the recommended N for wheat (*i.e*, PNBR75N, PNBR100N; PBBR75N, PBBR100N; PFBR75N, PFBR100N) during 2021-22. The CA-based permanent flat, broad, and narrow beds with anchored residue led to significant reduction in weed density and biomass at 60 days after sowing (DAS) and at harvest compared to ZT residue removal and CT treatments. These CA-based treatments considerably improved wheat growth indices, yield, and nutrient uptake. Among them, the CA-based PFBR100N and PBBR100N increased wheat grain yield by 14.1-15%, biological yield by 10.2-10.8% and total NPK uptake by 23-23.6% compared to CT and were most superior. The permanent beds with residue produced comparable wheat yields at 75%N and 100%N. Therefore, the permanent flat or broad bed with residue and 100%N in early years of CA adoption and 75%N in later years may be adopted for better weed control, higher crop growth and productivity of wheat in pigeonpea-wheat system.

Keywords: Conservation agriculture, Nutrient uptake, Productivity, Residue retention, Weed interference

Sustainable conservation agriculture (CA) practices characterized by integration of three basic principles: minimal or no mechanical disturbance, permanent surface residue cover, and crop diversification can improve crop production and promotes natural resource conservation (Kassam *et al*. 2019). The continued monoculture of conventional rice-wheat system (RWS) has resulted in yield plateauing in the major productive areas of the Indo-Gangetic Plains (IGP) (Das *et al.* 2014, 2020). The degradation of soil physical properties, soil fertility deterioration, and incidence of multi-nutrients deficiency led into poor resource use efficiency. Several CA-based resource conservation technologies, such as zero tillage (ZT), raised bed planting, crop residue retention, crop diversification with the inclusion of legumes in cropping system have been assessed as another possibility to conventional practices (Das *et al*. 2014, Bhattacharyya *et al*. 2015). Extra-short duration pigeonpea varieties such as Pusa 855 (135-140 days), and Pusa Arhar 16 (120 days) has opened the diversification options of RWS in IGP (Das *et al.* 2014). Diversified crop rotation including a legume, under CA can reverse soil deterioration, reduces pests/diseases infestations, improved weed management, sustains crop yield and quality (Li *et al.* 2019).

Weeds are one of the major constraints in crop production under both conventional till (CT) and zero till (ZT) systems, causing yield losses and impairs produce quality. Seed distribution, seedling recruitments varies across tillage practices and shift from annual to perennial or bigger-seeded to small seeded annuals had been noticed under CA (Govindasamy *et al*. 2020). The dynamics and diversity in emerged weeds population can provide an indicator of accomplishment in weed management practices. Therefore, the knowledge of weed seedling emergence and population dynamics across management practices is helpful in designing effective chemical and non-chemical weed management strategy for CA. Conservation tillage improves above and below ground crop growth, resource use efficiency and eventually crop yield

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(Das *et al.* 2018). According to Susha *et al.* (2018), adopting CA in wheat lowered the weed biomass by 14.0% and enhanced wheat yields by 6.9% over CT. Furthermore, CA system, in conjunction with precision nutrient management tools, can boost yield, nutrient use efficiency, and profitability while reducing environmental footprints from wheat production (Sapkota *et al*. 2014). Improved soil physical, chemical and biological properties coupled with better crop growth leads to better nutrient uptake and crop quality under CA (Ghosh *et al*. 2022). Therefore, this experiment was undertaken to evaluate the effect of tillage, crop residue retention, land configuration and N application on weed interference, crop growth, crop productivity, and nutrient uptake in wheat under a long-term CA-based pigeonpea-wheat system.

A field study was undertaken 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. At 0-15 cm soil depth, soil was sandy clay loam in texture (sand 48%, silt 24%, clay 28%) having pH 7.90-8.36, EC 0.22-0.35 dS/m, soil organic C 6.5-9.7 g/kg, $KMnO_4$ oxidizable N 253.7-291.7 kg/ha, 0.5M $NaHCO_3$ extractable P 73-95 kg/ha and 1 N NH_4OAc extractable K 436.2-599.8 kg/ha. Treatments were conventional till flatbed (CT), ZT permanent narrow bed (PNBR & PNB), broad bed (PBBR & PBB), and flatbed (PFBR & PFB) with and without residue (R). Further, residue retention treatments (PNBR, PBBR, PFBR) had 75% and 100% of the recommended N for wheat (*i.e.*, PNBR75N, PNBR100N; PBBR75N, PBBR100N; PFBR75N, PFBR100N) during 2021-22. To appraise changes in weed species due to CT and CA (through non-destructive method), a randomly selected area of 1 m × 1 m was earmarked/fixed in three locations of each CA and CT plots, and no herbicide was applied throughout crop growing period. The emerged weeds from those areas were counted and collected periodically until harvest of wheat crop (fixed-plot study). Except these fixed areas, the rest area of all CA and CT plots received a common application of the tank-mix of clodinafop-propargyl 60 g/ha + metsulfuron-methyl 5 g/ha at 35 DAS for weed control in wheat. For destructive weed sampling, a quadrat of 50 × 50 cm was randomly placed in three locations considering two wheat rows, and weed count was made replication-wise across CA and CT plots at 60 DAS (herbicide-treated plot study). The collected weed samples were sun-dried for three days and kept in an oven at 65˚C till constant weight obtained for estimating dry weight. Weed data were subjected to square-root $[(\sqrt{x+0.5})^{1/2}]$ transformation (Das 1999) to reduce inherent variation in data. Mean crop growth rate (CGR), mean relative growth rate (RGR), leaf area index (LAI) and harvest index (HI) were estimated using the equation 1-4 (Das, 2008).

$$\text{CGR (g/m}^2\text{/day)} = \frac{1}{p} * \frac{(w_2 - w_1)}{(t_2 - t_1)} \quad [1]$$

$$\text{RGR (g/g/day)} = \frac{(\ln w_2 - \ln w_1)}{(t_2 - t_1)} \quad [2]$$

$$\text{LAI} = \frac{\text{Leafarea (cm}^2)}{\text{Land area (cm}^2)} \quad [3]$$

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} * 100 \quad [4]$$

where w_2 and w_1 are the crop dry weight at t_2 and t_1 are days after sowing, respectively and $t_2 > t_1$.

Grain and biological yield were estimated from the net plot areas of 5 m^2 in flat bed and 7 m^2 in raised narrow and broad beds. The N, P, K uptake by wheat was calculated by multiplying nutrients concentrations with their respective grain and straw yield (Nath *et al*. 2015). Data were subjected to analysis of variance (ANOVA) for randomized complete block design using OPSTAT.

Weed interference

Weed species that existed after the common tank-mix application of clodinafop + metsulfuron to all CA and CT plots were *Phalaris minor* Retz. (grassy weeds); *Chenopodium album* L, *Coronopus didymus* L, *Melilotus indica* L, *Parthenium hysterophorus* L, *Sonchus oleraceous* L. (broad-leaved weeds); and *Cyperus esculentus* L. (sedge). Additionally, the emergence of some summer/rainy-season annual weeds such as *Dinebra retroflexa* L, *Setaria viridis* L, *Dactyloctenium aegyptium* L, *Eleusine indica* L. (grassy weeds), and *Polygonum aviculare* L. (broad-leaved weed) were found at harvest of wheat. It might be that these rainy/summer season weeds have gradually widened their ecological amplitude, leading to changes in their habit and getting adapted to occur in the seasonal transition period or in the season in which they used to rarely occur earlier. The probable effect of changing climate, particularly fluctuations/changes in temperature should not be ruled out/ ignored as well. After a common herbicide treatment to all plots, the destructive weed sampling done at 60 DAS revealed that the densities and dry weights of grassy and broad-leaved weeds (BLW) were drastically reduced and found non-significant across the treatments (**Table 1**). But, the density and biomass of sedges and total weed were significantly higher in CT treatment. The results confirmed findings of Tiwari *et al*. (2015) and Singh *et al*. (2017) in that this herbicide mixture controlled grassy and broad-leaved weeds effectively, but not sedges, which led to significantly higher sedge and total weed density in CT. At harvest, PBB had significantly higher grassy weed density and biomass, which was comparable with PBBR75N, PNB and PBBR100N (**Table 2**). This treatment also resulted in higher BLW density and biomass, which was at par with that in PNBR100N for weed density and PNBR75N, PNBR100N and PNB for weed biomass (**Table 2**). Sedges density and biomass, and total weed density were significantly higher in CT. Overall, the dominance of grassy and broad-leaved weeds was higher in ZT plots with or without residue retention, and the sedge density was significantly higher in CT treatment at harvest. Repeated application of glyphosate 1.0 kg/ha in zero tillage (ZT) practice during the short fallow period could have lowered the *C. esculentus* tubers population in CA soils. Moreover, crop residue retention and better crop stand supplemented with chemical weed management practices can contribute to weed suppression and weed seed bank exhaustion in CA over a long run. The PFBR100N, PFB, and PFBR75N were found more effective in reducing total weed density at harvest. However, the emerged weed seedlings at harvest under CT and CA can contribute to weed seed bank through seed rain during fallow period after wheat harvest. Therefore, tillage or non-selective herbicides under CT, and non-selective herbicides application under CA during fallow period may be advocated to manage the emerged weeds and restrict their seed accumulation.

Wheat growth, grain and biological yields and harvest index

Tillage, residue, land configuration and N management significantly influenced mean crop growth rate (CGR) and mean relative growth rate (RGR) at 0-30, 30-60, 60-90 and 90-130 DAS, and leaf area index (LAI) at 30, 60 and 90 DAS (**Table 3**). Residue retention had shown higher growth rates (CGR, RGR) than residue removal and CT. At 0-30 and 30-60 DAS, PFBR100N showed significantly higher CGR but all CA-based treatments (namely, PNBR75N, PNBR100N, PBBR75N, PBBR100N, PFBR75N and PFBR100N) and PFBR75N,

Table 1. Category-wise weed density and biomass in wheat across treatments at 60 DAS

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)			
	Grassy	Broad-leaved	Sedges	Total	Grassy	Broad-leaved	Sedges	Total
CT	0.9 (0.3)	2.6 (8.0)	6.1 (38.0)	6.7 (46.3)	0.74 (0.04)	0.96 (0.46)	1.42 (1.53)	1.58 (2.00)
PNB	1.2 (1.0)	2.7 (7.3)	4.2 (17.3)	5.1 (25.7)	0.79 (0.13)	0.97 (0.47)	1.04 (0.61)	1.30 (1.21)
PNBR75N	1.1 (0.7)	2.2 (4.7)	1.2 (1.3)	2.7 (6.7)	0.83 (0.20)	0.86 (0.24)	0.85 (0.26)	1.08 (0.70)
PNBR100N	0.7 (0.0)	2.3 (5.0)	0.7 (0.0)	2.3 (5.0)	0.71 (0.00)	0.86 (0.24)	0.71 (0)	0.86 (0.24)
PBB	1.2 (1.0)	2.2 (5.3)	3.4 (18.7)	4.4 (25.0)	0.81 (0.16)	0.85 (0.24)	0.89 (0.40)	1.07 (0.75)
PBBR75N	1.0 (0.7)	2.3 (6.0)	0.7 (0.0)	2.4 (6.7)	0.80 (0.15)	0.83 (0.2)	0.71 (0.00)	0.90 (0.34)
PBBR100N	1.0 (0.7)	2.4 (5.3)	0.7 (0.0)	2.5 (6.0)	0.78 (0.13)	0.81 (0.16)	0.71 (0.00)	0.88 (0.29)
ZTFB	0.7 (0.0)	1.2 (1.3)	1.2 (1.3)	1.7 (2.7)	0.71 (0.00)	0.73 (0.03)	0.73 (0.03)	0.75 (0.06)
ZTFBR75N	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
ZTFBR100N	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
LSD (p=0.05)	NS	NS	2.07	2.37	NS	NS	0.26	0.31

* Data are square-root transformed and the original values are in the parentheses

Table 2. Category-wise weed density and biomass in wheat across treatments at harvest

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)			
	Grassy	Broad-leaved	Sedges	Total	Grassy	Broad-leaved	Sedges	Total
CT	0.7 (0.0)	0.7 (0.0)	12.0 (148.0)	12.0 (148.0)	0.70 (0.00)	0.71 (0.00)	1.69 (2.40)	1.69 (2.40)
PNB	3.4 (12.0)	2.1 (4.0)	3.5 (16.0)	5.7 (32.0)	1.29 (1.16)	1.05 (0.60)	0.91 (0.40)	1.61 (2.10)
PNBR75N	2.8 (8.0)	1.9 (4.0)	3.7 (14.7)	5.2 (26.7)	1.05 (0.74)	1.16 (1.00)	0.80 (0.14)	1.44 (1.80)
PNBR100N	2.4 (5.3)	2.7 (6.7)	3.3 (12.0)	4.8 (24.0)	0.95 (0.42)	1.06 (0.60)	0.79 (0.13)	1.28 (1.20)
PBB	4.3 (18.7)	2.7 (6.7)	4.5 (22.7)	6.9 (48.0)	1.50 (1.82)	1.30 (1.20)	0.94 (0.40)	1.97 (3.40)
PBBR75N	4.0 (16)	1.7 (2.7)	3.1 (9.3)	5.3 (28.0)	1.49 (1.80)	0.87 (0.30)	0.85 (0.25)	1.64 (2.30)
PBBR100N	3.3 (10.7)	2.0 (4)	2.6 (8.0)	4.8 (22.7)	1.28 (1.17)	0.94 (0.40)	0.79 (0.10)	1.48 (1.70)
PFB	0.7 (0.0)	0.7 (0.0)	0.71 (0.0)	0.7 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
PFBR75N	0.7 (0.0)	1.3 (1.3)	0.71 (0.0)	1.3 (1.3)	0.71 (0.00)	0.76 (0.10)	0.71 (0.00)	0.76 (0.10)
PFBR100N	0.7 (0.0)	0.7 (0.0)	0.71 (0.0)	0.7 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
LSD(p=0.05)	1.11	1.02	2.52	1.82	0.38	0.31	0.29	0.51

* Data are square-root transformed and the original values are in the parentheses

PBBR100N, PBBR75N, PNBR100N were found comparable with it at 0-30 and 30-60 DAS, respectively. PBBR100N and PFBNR100N resulted in considerably higher CGR at 60-90 DAS and 90-130 DAS but found statistically at par with all ZT treatments except PNB. CA based treatments had 4.1-5.7%, 3.6-5.6%, 2.5-3.4%, 4.1-5.4% higher RGR than CT at 0-30, 30-60, 60-90 and 90-130 DAS, respectively. PFBR100N had shown higher RGR than other CA based treatments at 0-30, 30-60, and 90-130 DAS, whereas PBBR100N and PNBR75N were found superior at 60-90 DAS. The PFBR100N had significantly higher LAI at 30 DAS and found comparable with all residue retention plots including 75% and 100%N levels (**Table 4**). The PBBR100N had significantly higher LAI at 60 DAS and was comparable with PNBR100N, PBBR75N and PFBR100N in this regard. But, at 90 DAS, the PNBR100N had significantly higher LAI, which was comparable with those in all other CA based treatments (*i.e.* PNBR75N, PBBR75N, PBBR100N, PFBR75N, and PFBR100N). The CA-based residue retention treatments showed 28.6-42.9%, 14.6-31.7%, and 32.5-44.1% higher LAI than CT at 30, 60, and 90 DAS, respectively. Ghosh *et al.* (2022) have already reported higher growth rates owing to greater dry matter accumulation under CA.

Higher growth indices confirmed better growth in these treatments. Greater CGR, RGR and LAI under CA based treatments confirmed better growth and beneficial effects of residue retention compared to residue removal and CT. The ZT practices improved wheat grain yield by 8.1-14.9%, and biological yield by 4.9-10.8% over CT (**Table 4**). Among CA-based practices, PFBR100N led to significantly higher grain yield (5.37 t/ha) and biological yield (13.08 t/ha) and found comparable with all ZT practices with and without residue retention (PNBR75N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR75N, PNB, PBB and ZTFB). Harvest index did not vary significantly among the treatments. Similar results showing higher yield under CA were also reported by Das *et al*. (2014, 2018, 2020).

Nutrient uptake

The CA-based practices significantly improved N, P, and K uptake by wheat grain and straw (**Figure 1, 2, 3**). The ZT permanent beds with residue retention had significantly higher N, P, and K uptake than residue removal and CT. Also, the plots under residue retention and 100% N application showed greater nutrient uptake compared to treatments with 75% N application. Significantly higher uptake of N by wheat grain, straw and total N uptake (104.2, 28.1, 130.9 kg/ha N, respectively) were observed under the PFBR100N (**Figure 1**). Grain N uptake in this treatment (PFBR100N) was statistically at par with all ZT practices except PNB. For straw N uptake PBBR100N, PNBR100N, PFBR75N, PBBR75N, whereas for total N uptake, all CA based treatments were comparable. This PFBR100N registered 19.2, 27.7, 19.71% higher wheat grain, straw and total N uptake than CT, respectively. PBBR100N led to highest P uptake (17.1 kg/ha) by wheat grain and found statistically at par with all CA based treatments (**Figure 2**). Similarly, highest P uptake by straw (5.7 kg/ha) was recorded in PBBR100N, and comparable

Table 4. Wheat leaf area index (LAI), grain yield, biological yield and harvest index across the treatment

Treatment	LAI 30 DAS	LAI 60 DAS	LAI 90 DAS	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
CT	0.28	3.09	4.06	4.67	11.81	39.5
PNB	0.30	3.34	4.96	5.05	12.39	40.7
PNBR75N	0.36	3.54	5.58	5.21	12.77	40.8
PNBR100N	0.39	3.88	5.85	5.30	12.95	40.9
PBB	0.31	3.30	4.87	5.09	12.51	40.6
PBBR75N	0.36	3.96	5.54	5.26	12.86	40.9
PBBR100N	0.38	4.07	5.78	5.33	13.01	41.0
PFB	0.31	3.22	4.84	5.11	12.57	40.7
PFBR75N	0.37	3.64	5.38	5.28	12.90	40.9
PFBR100N	0.40	3.77	5.72	5.37	13.08	41.0
LSD(p=0.05)	0.04	0.33	0.84	0.39	0.68	NS

Table 3. Mean wheat crop growth rate (CGR) and mean relative growth rate (RGR) across treatments at different growth stages

Treatment	CGR (g/m^2/day)				RGR (g/g/day)			
	0-30 DAS	30-60 DAS	60-90 DAS	90-130 DAS	0-30 DAS	30-60 DAS	60-90 DAS	90-130 DAS
CT	1.29	11.59	15.19	9.52	0.122	0.195	0.204	0.148
PNB	1.34	14.32	15.68	10.97	0.123	0.202	0.205	0.152
PNBR75N	1.50	14.28	18.67	11.92	0.127	0.202	0.211	0.154
PNBR100N	1.53	15.04	18.44	12.37	0.127	0.204	0.210	0.155
PBB	1.35	13.71	16.61	11.28	0.123	0.201	0.207	0.153
PBBR75N	1.47	14.95	18.16	12.15	0.126	0.204	0.210	0.155
PBBR100N	1.54	14.99	18.74	12.53	0.128	0.204	0.211	0.155
PFB	1.39	14.05	17.33	11.42	0.124	0.201	0.208	0.153
PFBR75N	1.56	15.36	17.86	12.25	0.128	0.204	0.209	0.155
PFBR100N	1.59	16.07	18.27	12.70	0.129	0.206	0.210	0.156
LSD (p=0.05)	0.17	1.68	2.33	1.71	0.004	0.004	0.004	0.004

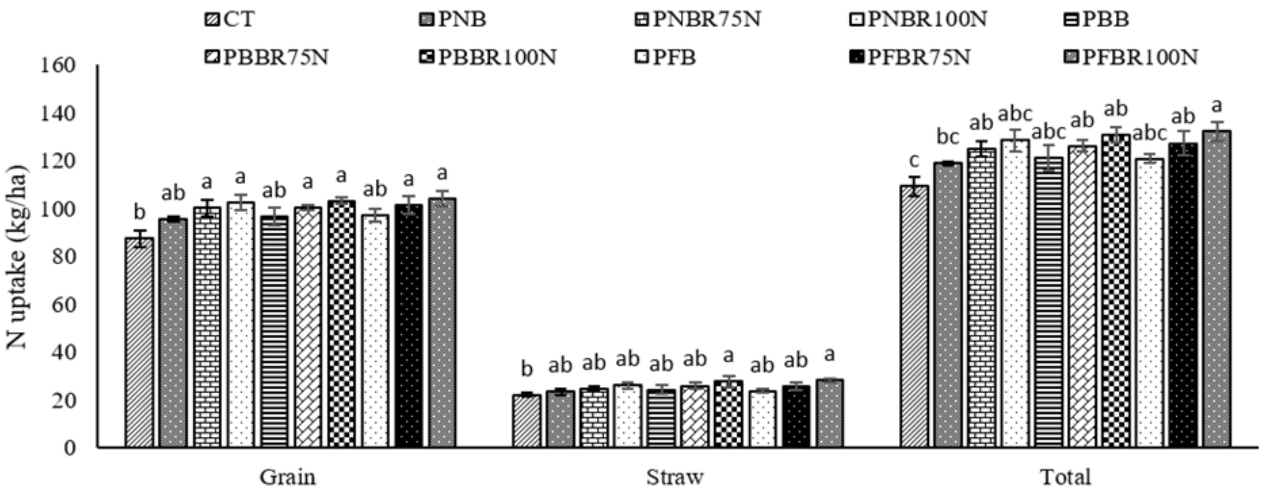

Figure 1. Wheat grain, straw and total N uptake across the treatments

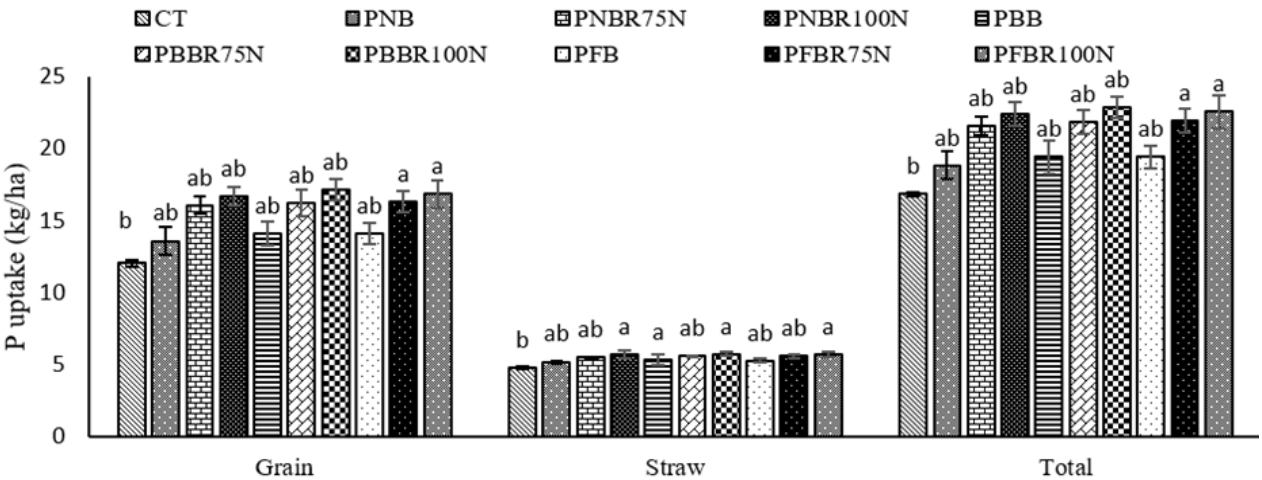

Figure 2. Wheat grain, straw and total P uptake across the treatments

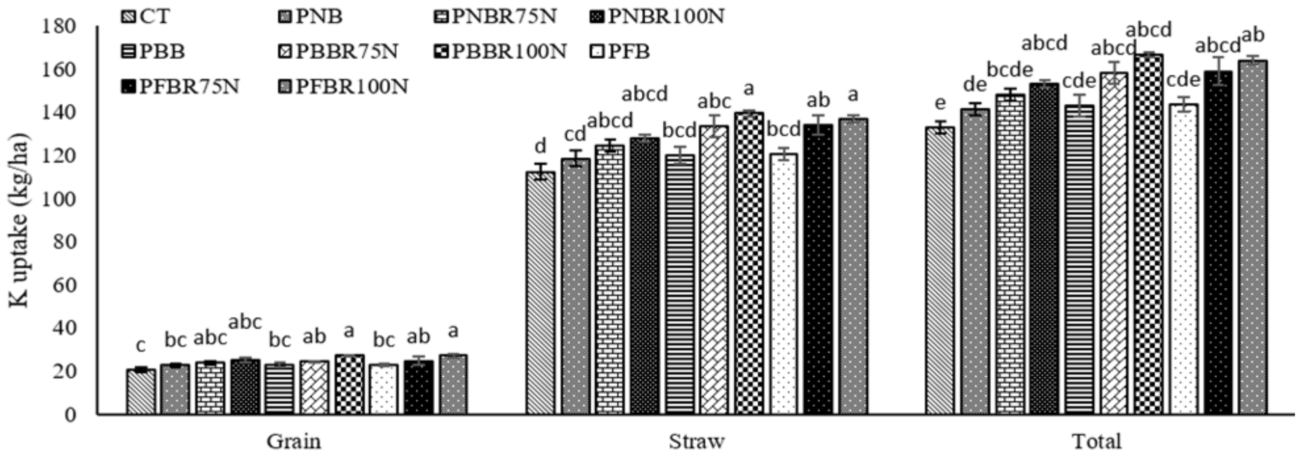

Figure 3. Wheat grain, straw and total K uptake across the treatments

values were obtained in all other ZT based treatments except PNB and ZTFB. This treatment resulted in 41.3, 20.8, 35.9% higher wheat grain, straw and total P uptake than CT, respectively. Again, PBBR100N resulted into significantly higher total P and K uptake. All CA based treatments showed comparable values for total P uptake whereas PFBR100N, PFBR75N, and PBBR75N were statistically at par with PBBR100N. Furthermore, significantly higher K uptake (27.2 kg/ha) by wheat grain was recorded under PBBR100N and found comparable with PFBR100N, PNBR100N, and PFBR75N (**Figure 3**). The same treatment showed highest K uptake by straw (139.7 kg/ha) and was comparable with

PFBR100N, PFBR75N, and PBBR75N in this regard. This treatment showed 32.7, 24.1, 25.5% higher wheat grain, straw and total K uptake than CT, respectively. The increased grain, straw and total nutrient uptake in CA may be attributed to improved root growth, greater foraging area under permanent beds, better soil physical, chemical and biological properties that led to more nutrient and water acquisition from nutrient-rich CA plots (Parihar *et al.* 2018; Ghosh *et al.* 2022). However, in CT practice the lower nutrient uptake might have resulted from higher weed infestation, nutrient losses, less soil water retention and impaired soil physical, chemical and biological properties and reduced crop yield (Nath *et al.* 2015, Das *et al.* 2018).

Results showed that seasonal boundary shift was noticed in some weeds' habit in CA and CT system. The CA-based ZT permanent bed with residue and N treatments, particularly PFBR100N, PFBR75N significantly lowered weed density and dry weight at harvest and restricted build-up of weed seed bank. Higher crop growth rates in terms of CGR, RGR, LAI under CA-base system improved grain and biological yields of wheat. CA based treatments had comparable yield at 75%N and 100%N application. The PFBR100N, PBBR100N, PFBR75N were found superior to other CA based practices for weed suppression, higher yield and nutrient uptake. Therefore, under CA based pigeonpea-wheat system, PFBR100N or PBBR100N at early years of CA adoption and 75%N treatments later years may be adopted in the Indo-Gangetic Plains of India and in similar agro-ecologies of the tropics and sub-tropics.

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