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# Productivity, nutrient uptake and nitrogen economy of wheat (*Triticum aestivum*) in a conservation agriculture-based cotton (*Gossypium herbaceum*)–wheat system

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ABSTRACT

Conservation agriculture (CA) practices like zero-till and residue retention along with nitrogen management is vital for improving degraded soil health and optimizing the yield potential of wheat (*Triticum aestivum* L.) crop. Present study was carried out during winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Indian Agricultural Research Institute, New Delhi for optimizing wheat productivity in a conservation agriculture-based cotton (*Gossypium herbaceum* L.)-wheat system. The experiment was laid out in a randomized complete block design (RCBD) with three replications consisting of combination of 3 different crop establishment methods, viz. permanent broad bed (PBB), permanent narrow bed (PNB) and zero-till flatbed (ZTFB) with residue (R) and without residue along with 2 doses of nitrogen (75N, 100N) and conventional tillage (CT). The CA-based practices showed overall superior response in terms of growth, yield and nutrients uptake of wheat than CT. Among them, the PBBR100N resulted in significantly higher plant height, leaf area index, dry-matter accumulation, crop growth rate, and relative growth rate compared to PNB, PBB, ZTFB and CT. This treatment led to significantly higher grain (16.2–19.4%) and straw (9.6–11.6%) yields than CT. The net returns and benefit cost ratio (23.4% and 27.9%) were also higher than that in CT. Again, in this treatment, N uptake by wheat crop was higher by 85%, P uptake by 53.1%, and K uptake by 40.1%, and available soil N, P and K by 16.1, 25.3 and 43.7%, respectively than CT. Therefore, the study suggests that the adoption of CA-based practices with broad bed in Indo-Gangetic Plains will not only enhance the productivity of wheat but also result in improved soil health by restoring soil fertility.

**Keywords**: Crop residue, Nitrogen saving, Permanent broad bed, Permanent flatbed, Permanent narrow bed, Zero tillage

The continuous practice of growing rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system under conventional tillage (CT) in Indo-Gangetic plains (IGP) resulted in degradation of soil. The puddling practices followed in rice led to destruction of soil aggregates and poor soil structure (Das *et al.* 2021). Rice and wheat are heavy feeders of nutrients and removes varying amounts of mineral nutrients from the top 30 cm soil, depending on production and nutrient-supplying capacity of the soil, which in turn is influenced by soil type, soil organic matter content, amount of nutrients applied and removed from the soil (Kumar *et al.* 2015). The rice-wheat system has not only resulted in mining of major nutrients (N, P, K and S) from soil, but also created a nutrient imbalance leading to deterioration in soil health and lowered the wheat productivity.

Conservation agriculture (CA) is a sustainable production system that helps in reviving the degraded soil by mainly focusing on the principles of zero-tillage, permanent soil cover and crop diversification. CA is adopted over 205 million hectares (Mha) across the world (Das *et al.* 2014, Kassam *et al.* 2022). The conservation of soil structure and fertility coupled with improved water retention, and its ability to mitigate greenhouse gas emissions and reduced need for synthetic inputs contributes to increased crop resilience in the face of climate change (Das *et al.* 2013). As agriculture grapples with the dual challenge of feeding growing population while minimizing its ecological footprint, CA emerges as promising paradigm that not only addresses current agricultural issues but also fosters long-term sustainability (Sahu *et al.* 2020). Adoption of crop

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establishment methods like permanent broad bed and narrow bed systems offer advantages in terms of productivity and nutrient uptake compared to traditional flatbed systems. These advantages stem from improved soil structure, water management, and optimized plant spacing, which contributes to better root development and nutrient utilization by crops.

Therefore, the present study was carried out to unravels the advantages of conservation agriculture combined with various crop establishment methods and nitrogen management in optimizing the growth of wheat and fertility status of soil, making it a focal point in the quest for a more resilient and eco-conscious agriculture.

## MATERIALS AND METHODS

The present study was carried out during the winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Indian Agricultural Research Institute, New Delhi (28°35′ N, 77°12′ E and altitude of 228.6 m amsl) under the ongoing research trial of long-term conservation agriculture in cotton-wheat system since 2010. The soil had a sandy clay loam texture with *p*H=7.75–8.42, EC=0.24–0.36 dS/m, organic C=0.68–0.97%, available N=272–318 kg/ha, available P=75–99 kg/ha and K= 408–589 kg/ha at 0–15 cm soil depth. The experiment was laid out using randomized complete block design (RCBD) with three replications. The treatments comprised of 3 crop establishment methods, viz. permanent broad bed (PBB) (110 cm wide, 15 cm height followed by 30 cm furrow); permanent narrow bed (PNB) (40 cm wide, 15 cm height followed by 30 cm furrow); and zero-till flatbed (ZTFB), with residue (R) and without residue retention along with 2 doses of nitrogen (100% of recommended dose of nitrogen i.e. 150 kg N/ha and 75% of recommended dose of nitrogen i.e. 112.5 kg N/ha) and conventional tillage (CT). In the plots with residue retention, 20% of previous crop (cotton) residues were retained. Tillage practices were carried out only in CT. Permanent beds were laid out in 2010 and maintained all through the years of experiments. Sowing of wheat variety HD-3117 was done on 21$^{th}$ November 2021 and 23$^{th}$ November 2022 at a row spacing of 22.5 cm. The recommended doses were 150 kg N, 60 kg $P_2O_5$, and 40 kg $K_2O$/ha, which was uniformly applied to all plots, except in the 75% N level plots where 112.5 kg N/ha was applied. The entire amounts of P and K along with 50% of the N as per the treatment were applied during sowing. The remaining 50% N was top-dressed in two equal splits during tillering and flowering stages. Five and six irrigations were given to wheat during first and second year, respectively, based on soil moisture deficits. Glyphosate @1.0 kg/ha was applied as a pre-plant spray before wheat sowing to manage existing weeds. A tank-mix application of 5 g/ha metsulfuron methyl + 60 g/ha clodinafop-propargyl was done at 30 days after sowing (DAS) in wheat to control both grassy and broad-leaved weeds. To estimate plant height, five plants were randomly tagged and height was measured. Leaf area meter was used for measuring leaf area index. A 50 cm row of continuous plant stand was randomly selected from three different locations in each plot for estimating dry weight. The mean crop growth rate and relative growth rate were worked out at different growth stages as per Blackman (1919) and Watson (1952), respectively. To determine wheat grain and straw yields, a net plot area of 7 m × 5 m was harvested manually and dried under sun for three days followed by threshing in a thresher. The threshed grains were cleaned and grain yield was measured at 12% moisture content. Nitrogen content of plant samples was determined by modified kjeldahl method, P content by vanadomolybdophosphoric acid yellow colour method, and K content by flame photometer method (Jackson 1973).

Nutrient uptake (kg/ha) was calculated as:

$$\text{Nutrient uptake}=[\{(\%\text{ Nutrient} \times \text{Grain yield})+(\%\text{ Nutrient} \times \text{Straw yield})\}\div 100]$$

The economic analysis was calculated as:

$$\text{Net returns} = \text{Gross returns} - \text{Cost of cultivation}$$

$$\text{BCR} = \frac{\text{Net returns}}{\text{Total cost of cultivation}}$$

The analysis of variance of data was done for a randomized complete block design (RCBD) and the least significant difference (LSD) was determined to compare the treatment means at 5% level of significance.

## RESULTS AND DISCUSSION

*Agronomic growth parameters of wheat*: Conservation agriculture-based practices showed improved growth in terms of plant height, dry matter production and leaf area index than conventional tillage practices during both the years. Plant height of wheat increased with increase in crop age and the highest plant height at 60 DAS during both the years was recorded in the treatment PBBR100N (60.8 cm) which was found to be significantly higher than treatments without residue addition and CT (Table 1). The increased plant height is due to the combined effects of zero tillage and residue retention that helped in better germination and establishment of crop. The raised broad bed method helped in maintaining congenial conditions for the crop to emerge and grow by providing optimum moisture content, good soil structure with proper drainage and aeration compared to flat and tilled beds. Apart from the establishment methods, addition of residue increased the availability of nutrients, moderated soil temperature for optimum growth of plants. Leaf area index, an important indicator of photosynthetic potential of plant canopy which is often correlated with biomass production was observed highest in the treatment PBBR100N (1.57 at 60 DAS) (Table 1). A similar trend was observed in dry matter production at 60 DAS during both the years. Zero tillage with residue retention improved crop growth, attributed to long-term favourable impacts, including earlier germination and better crop establishment. Raised broad-beds maintain favourable soil moisture, moderate soil temperature, and enhance soil nutrient status. Crop residues in zero tillage prevent soil crusting,

Table 1 Impact of conservation agriculture practices on plant height, dry-matter production, leaf area index and yield of wheat during 2021–22 and 2022–23

| Treatment | Plant height (cm) | | Dry matter production (g/m$^2$) | | Leaf area index (at 60 DAS) | | Grain yield (t/ha) | | Straw yield (t/ha) | | Biological yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 |
| CT | 52.3 | 50.4 | 386.2 | 367.4 | 1.46 | 1.40 | 4.58 | 4.42 | 7.02 | 6.97 | 11.60 | 11.39 |
| PNB | 54.4 | 52.8 | 394.4 | 371.5 | 1.48 | 1.43 | 4.84 | 4.76 | 7.21 | 7.20 | 12.05 | 11.96 |
| PNBR75N | 57.8 | 62.4 | 405.5 | 401.8 | 1.50 | 1.49 | 5.10 | 5.11 | 7.51 | 7.42 | 12.61 | 12.53 |
| PNBR100N | 58.2 | 57.9 | 412.9 | 405.4 | 1.52 | 1.50 | 5.27 | 5.14 | 7.65 | 7.59 | 12.92 | 12.73 |
| PBB | 55.9 | 53.6 | 396.8 | 382.4 | 1.49 | 1.47 | 4.92 | 4.98 | 7.33 | 7.38 | 12.25 | 12.36 |
| PBBR75N | 58.7 | 58.1 | 416.2 | 412.3 | 1.54 | 1.51 | 5.24 | 5.19 | 7.78 | 7.64 | 13.02 | 12.83 |
| PBBR100N | 60.8 | 59.0 | 428.4 | 416.4 | 1.57 | 1.55 | 5.32 | 5.28 | 7.91 | 7.78 | 13.23 | 13.06 |
| ZTFB | 54.7 | 52.4 | 392.5 | 375.1 | 1.49 | 1.45 | 4.79 | 4.74 | 7.19 | 7.14 | 11.98 | 11.88 |
| ZTFBR75N | 56.3 | 57.3 | 404.5 | 399.5 | 1.49 | 1.50 | 5.07 | 5.01 | 7.49 | 7.52 | 12.56 | 12.53 |
| ZTFBR100N | 58.9 | 58.5 | 409.6 | 403.4 | 1.54 | 1.53 | 5.18 | 5.09 | 7.53 | 7.60 | 12.71 | 12.69 |
| SEm ± | 1.54 | 2.23 | 13.79 | 14.49 | 0.02 | 0.02 | 0.08 | 0.06 | 0.15 | 0.13 | 0.19 | 0.12 |
| LSD (*P*=0.05) | 4.58 | 6.63 | 40.97 | 43.04 | 0.06 | 0.06 | 0.25 | 0.19 | 0.44 | 0.38 | 0.57 | 0.36 |

CT, Conventional tillage; PNB, Permanent narrow bed; PNBR75N, Permanent narrow bed with residue + 75% recommended dose of nitrogen; PNBR100N, Permanent narrow bed with residue + 100% recommended dose of nitrogen; PBB, Permanent broad bed; PBBR75N, Permanent broad bed with residue + 75% recommended dose of nitrogen; PBBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; ZTFB, Zero tillage flatbed; ZTFBR75N, Zero tillage flatbed with residue + 75% recommended dose of nitrogen; ZTFBR100N, Zero tillage flatbed with residue + 100% recommended dose of nitrogen. DAS, Days after sowing.

decrease compaction and temperature, retain moisture, improve soil structure, and enhance root development, SOC sequestration, stability, and microbial health. Furthermore, CA-based residue retention practices resulted in lesser weed interference owing to residue retention when compared to CA-based residue removal treatments and CT practice which contributed to higher leaf growth and increased dry matter accumulation in residue retention plots. In case of CT without residue addition led to carbon and nutrient loss, faster soil moisture evaporation, poor germination, and reduced crop development which resulted in lower dry matter production. Similar results were observed by Saad *et al.* (2016) and Das *et al.* (2022).

*Physiological growth rates of wheat*: The inspection of experimental data revealed that the imposed treatments produced marked variation in growth rates of wheat (Fig. 1 and 2). Crop growth rate curve showed an increasing trend being low at 0–30 DAS followed by gradual increase at 30–60 DAS and thereafter a steep rise till 90 DAS. The relative growth rate curve (mg/g/day) of wheat showed a decreasing trend with highest values during initial period of 0–30 DAS and thereafter decreased with increased duration of the crop. However, conservation agriculture practices maintained higher CGR and RGR throughout the crop growth stages compared to CT and treatments without residue retention (Fig. 1 and 2).

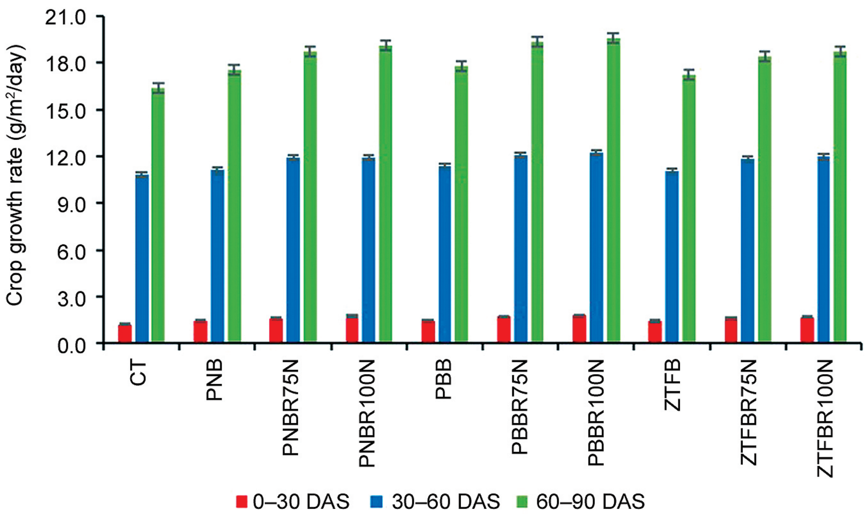


Fig. 1 Effect of conservation agriculture practices on wheat crop growth rate (mean of two years).
CT, Conventional tillage; PNB, Permanent narrow bed; PNBR75N, Permanent narrow bed with residue + 75% recommended dose of nitrogen; PNBR100N, Permanent narrow bed with residue + 100% recommended dose of nitrogen; PBB, Permanent broad bed; PBBR75N, Permanent broad bed with residue + 75% recommended dose of nitrogen; PBBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; ZTFB, Zero tillage flatbed; ZTFBR75N, Zero tillage flatbed with residue + 75% recommended dose of nitrogen; ZTFBR100N, Zero tillage flatbed with residue + 100% recommended dose of nitrogen. DAS, Days after sowing.

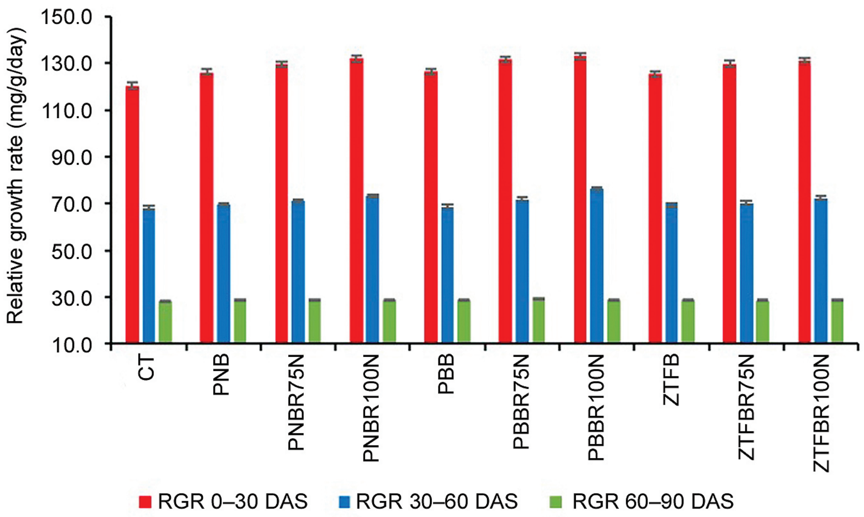


Fig. 2 Effect of conservation agriculture practices on wheat relative growth rate (RGR) (mean of two years).
CT, Conventional tillage; PNB, Permanent narrow bed; PNBR75N, Permanent narrow bed with residue + 75% recommended dose of nitrogen; PNBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; PBB, Permanent broad bed; PBBR75N, Permanent broad bed with residue + 75% recommended dose of nitrogen; PBBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; ZTFB, Zero tillage flatbed; ZTFBR75N, Zero tillage flatbed with residue + 75% recommended dose of nitrogen; ZTFBR100N, Zero tillage flatbed with residue + 100% recommended dose of nitrogen. DAS, Days after sowing.

Among the CA-based practices, PBBR100N showed 13.9% higher CGR and 11.77% higher RGR than CT plots at 30–60 DAS. The results indicated that the increased growth rates of wheat by CA practices is due to direct and residual effect of better nutrition availability which gave initial boost to the crop that led to higher dry matter accumulation and resulted in higher CGR and RGR values under conservation agriculture. Kumar *et al.* (2013) and Hati *et al.* (2015) reported almost similar results in maize and wheat, respectively.

*Grain, straw and biological yields of wheat*: The CA-based practices improved wheat grain yield to the tune of 16.2%, straw yield up to 9.6% and 14.1% higher biological yield during 2021–22, while in 2022–23, it resulted in 19.4%, 11.6% and 14.6% higher grain, straw and biological yields than CT (Table 1). Higher grain yield in wheat under CA-based residue retained practices was due to increased photosynthesis and efficient translocation of photosynthates, as well as a larger sink and a stronger reproductive phase. The contrast analysis between permanent broad beds and flatbed showed significant difference in grain yield during both the years (Table 2). The increased yield among CA-based broad bed planting was due to retention of more residues on top of the beds than narrow and flatbeds. The crop rows of wheat seeded on the edges of beds and closer to the furrows under PBBR did not face water stress mainly because of favourable mulching effects of crop residues. A significant variation in yield between residue and no residue retention as shown by contrast analysis is the retention of residue resulted in greater infiltration, higher soil moisture conservation on beds, reduced run-off and erosion, better temperature moderation, inhibition of weed proliferation and more soil microbial activity resulting in biological tillage under PBBR with comparison to PNBR, ZTFBR and other treatments without residues and CT (Das *et al.* 2020, Baghel *et al.* 2020). All these factors together contributed to increased crop yield under PBBR100N.

*Economics*: The treatment PBBR100N registered 25.3% higher net returns, 22.9% higher B:C than CT (Fig. 3). PBBR100N resulted in significantly higher net returns whereas, CA-based practices with no residue retention registered significantly higher net B:C as these did not involve cost of residue application, but these treatments were found to be comparable with other treatments with residue retention.

Table 2 Contrast analysis of wheat yield (t/ha) during 2021–22 and 2022–23

| 2021–22 | | | 2022–23 | | |
|---|---|---|---|---|---|
| CA | CT | *P* value | CA | CT | *P* value |
| 5.26$^{a}$ (14.8) ↑ | 4.58$^{b}$ | <.0001 | 5.17$^{a}$ (16.9) ↑ | 4.42$^{b}$ | <.0001 |
| *100N* | *75N* | P *value* | *100N* | *75N* | P *value* |
| 5.26$^{a}$ | 5.14$^{a}$ | 0.0967 | 5.17$^{a}$ | 5.11$^{a}$ | 0.2390 |
| *PBBR* | *ZTFBR* | P *value* | *PBB* | *FB* | P *value* |
| 5.16$^{a}$ (2.9) ↑ | 5.01$^{b}$ | 0.0447 | 5.15$^{a}$ (4.0) ↑ | 4.95$^{b}$ | 0.0012 |
| *R* | *NR* | P *value* | *R* | *NR* | P *value* |
| 5.20$^{a}$ (7.2) ↑ | 4.85$^{b}$ | <.0001 | 5.14$^{a}$ (6.4) ↑ | 4.83$^{b}$ | <.0001 |

CA, Conservation agriculture; CT, Conventional tillage; 100N, 100 per cent recommended dose of nitrogen; 75N, 75 per cent recommended dose of nitrogen; PBBR, Permanent broad bed with residue; ZTFBR, Zero tillage flatbed with residue; PBB, Permanent broad bed; FB, Flatbed; R, Residue; NR, Without residue.

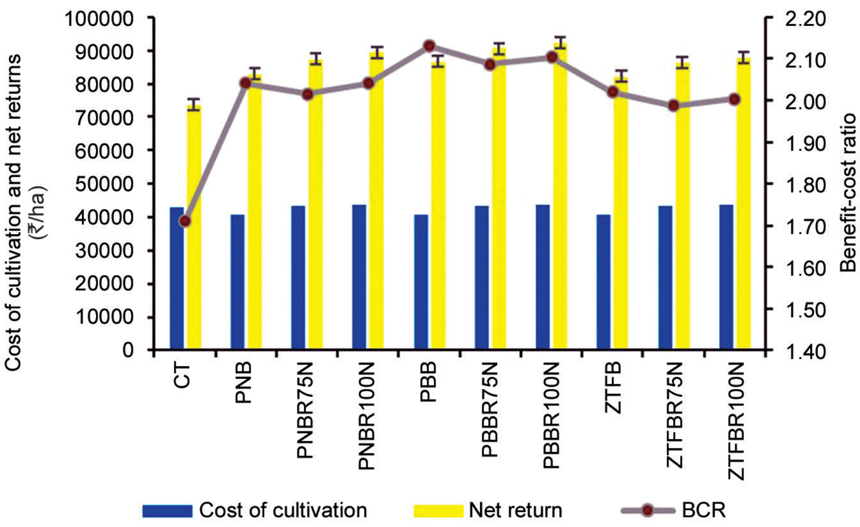


Fig. 3 Effect of conservation agriculture practices on net returns and benefit-cost ratio (BCR) of wheat (mean of two years).
CT, Conventional tillage; PNB, Permanent narrow bed; PNBR75N, Permanent narrow bed with residue + 75% recommended dose of nitrogen; PNBR100N, Permanent narrow bed with residue + 100% recommended dose of nitrogen; PBB, Permanent broad bed; PBBR75N, Permanent broad bed with residue + 75% recommended dose of nitrogen; PBBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; ZTFB, Zero tillage flatbed; ZTFBR75N, Zero tillage flatbed with residue + 75% recommended dose of nitrogen; ZTFBR100N, Zero tillage flatbed with residue + 100% recommended dose of nitrogen.

*Nitrogen economization/saving*: The contrast analysis between treatments having 100N and 75N doses was found non-significant, indicating on par of grain, straw and biological yields of wheat demonstrating 25% N savings (Table 1 and 2).

*Nutrient uptake and available soil nutrients*: CA practices had a greater influence on nutrient uptake of wheat than CT. The treatment PBBR100N resulted in increased total nutrient uptake of all the three major nutrients N, P and K during both the years 2021–22 and 2022–23 (Table 3). However, the uptake of nutrients was found on par with all the residue retained plots and significantly higher than plots without residue and CT. Residue retention as surface mulch, along with nutrient application to the wheat crop, resulted in a superior soil medium for crop root development which further helped in uptake of nutrients from deeper layers of soil. The residue removal treatments were not found beneficial compared to treatments with residue retention in this regard. The CA-based practices registered 55.5–85.8% higher uptake for N, 19.4–32.6% higher for P and 28.2–53.1% higher uptake of K, respectively than CT in first year and a similar trend was seen during the second year. In case of available nutrients in soil, results showed significantly higher values of available N, P and K in CA-based practices with residue retention as compared to treatments with no residue (Table 3). It was also observed that among N doses, the plots with residue and 100% N

Table 3 Impact of conservation agriculture practices on nutrient uptake of wheat, partial factor productivity of N (PFPN) and soil nutrient status after 2023

| Treatment | N uptake (kg/ha) | | P uptake (kg/ha) | | K uptake (kg/ha) | | $PFP_N$ (kg grain/kg N) | | Available N (kg/ha) | Available P (kg/ha) | Available K (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 | 2021–22 | 2022–23 | | | |
| CT | 81.4 | 79.6 | 24.3 | 22.6 | 117.4 | 119.6 | 30.5 | 29.5 | 272.4 | 75.22 | 282.1 |
| PNB | 101.2 | 99.1 | 26.6 | 27.9 | 129.9 | 132.4 | 32.3 | 31.7 | 290.5 | 83.8 | 293.3 |
| PNBR75N | 131.2 | 127.6 | 33.3 | 33.0 | 151.0 | 152.8 | 45.3 | 45.5 | 326.8 | 90.4 | 307.5 |
| PNBR100N | 142.0 | 139.6 | 35.2 | 34.9 | 156.6 | 161.5 | 35.1 | 34.3 | 336.2 | 92.6 | 314.5 |
| PBB | 110.3 | 106.2 | 28.9 | 29.9 | 137.0 | 142.3 | 32.8 | 33.2 | 294.8 | 84.7 | 302.4 |
| PBBR75N | 134.4 | 131.9 | 35.2 | 34.8 | 155.7 | 160.2 | 46.6 | 46.1 | 329.8 | 97.2 | 315.4 |
| PBBR100N | 151.3 | 145.1 | 37.2 | 37.3 | 165.4 | 169.6 | 35.5 | 35.2 | 341.5 | 99.7 | 336.1 |
| ZTFB | 98.4 | 100.5 | 26.9 | 27.1 | 129.2 | 134.6 | 31.9 | 31.6 | 287.6 | 82.5 | 297.6 |
| ZTFBR75N | 126.6 | 124.2 | 32.5 | 31.9 | 150.5 | 155.7 | 45.1 | 44.6 | 327.1 | 89.8 | 308.7 |
| ZTFBR100N | 139.4 | 137.3 | 33.9 | 34.1 | 157.8 | 163.2 | 34.5 | 33.9 | 338.7 | 90.4 | 328.2 |
| SEm ± | 8.91 | 7.42 | 1.76 | 1.95 | 4.95 | 5.83 | 2.06 | 1.86 | 5.41 | 2.81 | 7.28 |
| LSD (*P*=0.05) | 26.2 | 22.5 | 5.1 | 5.7 | 14.9 | 17.2 | 6.18 | 5.57 | 16.08 | 8.42 | 21.64 |

CT, Conventional tillage; PNB, Permanent narrow bed; PNBR75N, Permanent narrow bed with residue + 75% recommended dose of nitrogen; PNBR100N, Permanent narrow bed with residue + 100% recommended dose of nitrogen; PBB, Permanent broad bed; PBBR75N, Permanent broad bed with residue + 75% recommended dose of nitrogen; PBBR100N, Permanent broad bed with residue + 100% recommended dose of nitrogen; ZTFB, Zero tillage flatbed; ZTFBR75N, Zero tillage flatbed with residue + 75% recommended dose of nitrogen; ZTFBR100N, Zero tillage flatbed with residue + 100% recommended dose of nitrogen.

obtained higher values of available N, P and K in soil in comparison to treatments with residue and 75% N, plots without residue and CT. PBBR100N significantly had higher available N (341.5 kg/ha) among all the practices and registered 25.36% higher N than CT. However, it was found at par with all CA-based practices with residue retention. Similar trend was observed with other nutrients also, viz. available P and K which are 43.7% and 19.1% higher than CT, respectively. Results indicated the superiority of residue retained treatments in increasing available N, P and K in soil under cotton-wheat system. CA-based broad bed method of planting with residue improved the crop root development compared to narrow-bed and flat-bed planting practices. Also, application of 100% N in PBBR aid in the decomposition of previous crop residues, resulting in enhanced availability of nutrients for uptake by the crop (Sepat *et al.* 2015).

*Nitrogen use efficiency (NUE)*: NUE in terms of partial factor productivity of nitrogen ($PFP_N$) was significantly higher in conservation agriculture (CA) compared to conventional tillage (CT). However, significant variations were observed within CA-based practices also. CA treatments without residue recorded higher NUE than CT, but lower than residue retained treatments. Among CA practices with residue, those with 75% N displayed significantly higher NUE than 100% nitrogen. PBBR75N registered significantly higher $PFP_N$ during both the years and was on par with treatments having 75% N. Application of 75% recommended dose of N increased NUE as the yield gains with 100% N were found at par and saved 25% N.

The conservation agriculture-based practices adopted in this study have shown notable improvements in the growth, yield, and economics of wheat along with higher nutrients uptake and available soil nutrients. Specifically, the CA practice that integrated zero till permanent broad bed and residue retention resulted in a remarkable 25% reduction in nitrogen usage, demonstrating significant savings without compromising wheat productivity. The enhanced nutrient uptake by wheat crop and higher available nutrients in soil further underscore the positive impact of CA on optimizing agricultural resources and restoring soil health. Further, reduced application of nitrogen under CA may lead to lower emission of greenhouse gases, particularly $N_2O$, and impart adaptation mitigation co-benefit.

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