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Impact of Conservation Agriculture on Wheat Growth, Productivity and Nutrient Uptake in Maize–Wheat–Mungbean System

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ABSTRACT

Conservation agriculture (CA) involving minimum mechanical soil disturbance, permanent soil cover with crop residue mulch and diversified crop rotation, plays a crucial role in sustainable crop production. A field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during *rabi* seasons (November–April) of 2018–19 and 2019–20 in wheat involving maize-wheat-mungbean system to assess the effects of CA on crop productivity, nutrient uptake and profitability. Results showed that CA-based practices with residue retention resulted in higher yield as well as economic benefits when compared to conventional tillage (CT). Wheat yield parameters in CA were greater than in CT. The CA-based practices improved wheat grain and straw yield to the tune of 7.2–27.1% and 5.7–20.6%, respectively compared to CT practice. The CA-based practices with residue retention with 100% N registered 9.7% higher cost of cultivation, but resulted in 24.3–35.1% higher net returns than CT. Among CA-based practices, the plots under permanent broad bed with residue with 100% N (PBB+R+100N) resulted in ~27% higher wheat grain yield compared to CT. The PBB+R+100N plots also had considerably greater nutrient uptake and net returns than CT plots. The CA practice involving PBB+R+100N was found to be more productive, remunerative and could potentially boost up the wheat productivity and profitability under maize-wheat-mungbean system in north-western Indo-Gangetic Plains of India.

KEYWORDS: Conservation agriculture, conventional tillage, nutrient uptake, wheat, yield

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1. INTRODUCTION

Conservation agriculture (CA) is based on three interrelated principles, such as no or minimum mechanical soil disturbance, biomass mulch soil cover and crop species diversification, in addition to other good agricultural practices (Kassam et al., 2019). CA is being advocated in order to boost agricultural yield while also ensuring environmental sustainability (Hobbs et al., 2008). The maize (*Zea mays* L.)–wheat (*Triticum aestivum* L. emend Fiori and Paol)–mungbean (*Vigna radiata* L.) cropping system is being promoted as an alternative to existing rice-based cropping systems of the northwestern Indo-Gangetic Plains in order to overcome the challenges such as energy and nutritional scarcity, residue burning, reduction in biomass productivity and water table decline (Ladha et al., 2003; Chauhan et al., 2012; Choudhary et al., 2017; Parihar et al., 2017). Conservation tillage improves crop root growth, water and nutrient use efficiencies and eventually the agronomic yield (Das et al., 2018; Ghosh et al., 2019, 2021). In north-west India, CA-based management with diversified maize–wheat–mungbean system was found to be an effective substitute for conventional rice-wheat system in terms of productivity, profitability and energy indices (Jat et al., 2020). Sharma et al. (2012) found that wheat grain yields were comparable under conventional and zero tillage (ZT). Ghosh et al. (2015) advocated that adoption of CA could increase productivity, achieve better economic benefits and regulate soil erosion. They discovered that in a maize–wheat crop rotation, the mean wheat equivalent yield was 47% higher in the CA plots than in the conventional plots. According to Jat et al. (2020), CA-based rice–wheat and maize–wheat systems increased crop productivity by 10% and 16%, respectively and profitability by 34% and 36% when compared to CT. After three years of ZT wheat cultivation, Kumar et al. (2013) reported a 33% increase in net income compared to CT. 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. Furthermore, it increased maize-wheat system productivity by 5.4 and 7%, respectively, over CT and ZT without residue. ZT has the potential to reduce the amount of soil organic carbon (SOC) from the soil profile by slowing macro-aggregate turnover, increasing the physical protection of particulate organic material and lowering the contact between soil and crop residues (Page et al., 2020). Choudhary and Baker (2017) opined that regardless of the potential negative outcomes during the first few years of ZT, long-term ZT would reap advantages such as lower fertilizer requirements, pest protection and enhanced crop productivity. The surface retention of crop residue in ZT could be more successful than residue incorporation in CT for crop production and economic profitability (Nath et al., 2018). In comparison to CT practice, adopting CA for 6–7 years results in improved soil aggregation in the surface layer and lowers subsurface soil compaction (Das et al., 2014; Mondal et al., 2019). Diversified crop rotation, including a legume crop under CA, can improve soil fertility, reduce pests/diseases and increase crop yield stability (Li et al., 2019). The ZT system, in conjunction with site-specific techniques for nutrient management, can boost yield, nutrient use efficiency, and profitability while reducing greenhouse gas emissions from wheat production (Sapkota et al., 2014). Crop residue retention on the soil surface in conjunction with ZT leads to enhanced soil quality and overall resource enhancement (Ghuman and Sur, 2001; Chen et al., 2011; Das et al., 2013). The objective of this study was to compare the effects of conventional tillage and conservation agriculture-based crop establishment practices on crop productivity, nutrient uptake and economics of growing wheat as a component crop in a maize–wheat–mungbean system.

2. MATERIALS AND METHODS

The field experiments were conducted during the *rabi* seasons (November–April) of 2018–19 and 2019–20 at Research Farm, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°35' N latitude, 77°12' E longitude and an altitude of 228.6 meters above mean sea level), India. The soil of the experimental site 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 soil samples were analyzed following the methods outlined by Jackson (1973). 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. 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 CT 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 1st fortnight of November 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.

Wheat growth parameters such as plant height and dry matter accumulation were studied at 30, 60 and 90 days after sowing (DAS). Twenty ear heads from sampled plants were randomly selected, threshed manually and number of grains per ear head was counted. 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}. In wheat, nutrient uptake was calculated as described by Nath et al. (2015). The cost of cultivation under various treatments was calculated using current market prices for the various inputs used in the treatments. The data on crop growth, productivity, nutrient uptake and economics were subjected to pooled analysis. To determine the statistical significance of treatment effects, the data was analyzed using analysis of variance (ANOVA) in a randomized completed block design using R (version 4.0.5) statistical software (Anonymous, 2013). The Tukey Multiple Comparison Test was used to test for treatment differences at a 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. *Wheat growth and yield variables*

Tillage, residue, crop establishment and N management practices had significant impacts on growth parameters of wheat such as plant height and dry matter accumulation at 30, 60 and 90 DAS during 2018–19 and 2019–20. The CA-based practices outperformed CT practice in increasing growth parameters of wheat. Residue retention improved wheat growth characteristics. Among CA-based practices, the plots under PBB+R+100N significantly improved the growth parameters of wheat throughout different growing stages. Significantly higher plant height was registered under both the treatments PBB+R+100N and FB+R+100N at 30 DAS (Table 1). At 60 and 90 DAS, significantly higher plant height was obtained under the treatment PBB+R+100N. However, it was found comparable with all the CA-based residue retained treatments at 60 and 90 DAS. The treatment FB+R+100N resulted in significantly higher dry matter accumulation in wheat at 30 DAS, whereas the treatment PBB+R+100N led to increased dry matter accumulation at 60 and 90 DAS (Figure 1). The higher values of plant height and dry matter accumulation in residue retained treatments confirmed better growth and beneficial effects of residue retention as compared to CA-based residue removal treatments as well as CT.

Table 1: Plant height in wheat across treatments

Treatments	Plant height (cm)		
	30 DAS	60 DAS	90 DAS
CT	24.2	57.4	99.9
PNB	26.0	62.2	102.7
PNB+R+75N	27.4	65.5	105.6
PNB+R+100N	29.3	67.3	107.9
PBB	26.2	63.0	103.2
PBB+R+75N	27.7	66.1	106.8
PBB+R+100N	30.3	68.3	109.0
FB	25.3	63.7	103.7
FB+R+75N	27.7	65.9	106.1
FB+R+100N	30.3	68.1	108.4
SEm±	0.3	1.1	1.3
CD (p=0.05)	0.9	3.3	3.8

Refer materials and methods for treatment details

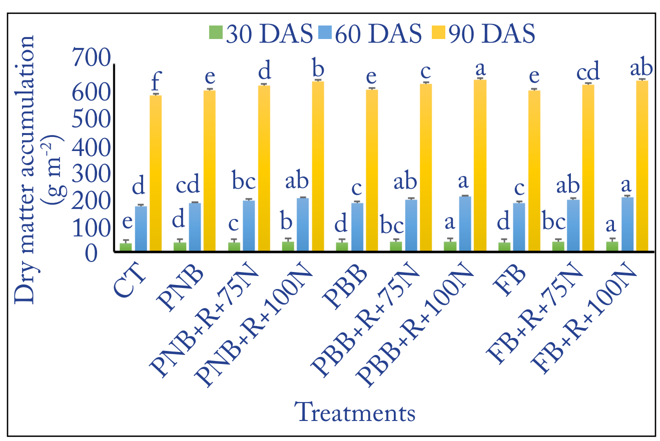

Figure 1: Dry matter accumulation in wheat across treatments

Crop growth was improved by zero tillage, which might be attributed to its long-term favourable impacts with residue retention. This could be attributed to earlier germination and better establishment of wheat on zero tillage and raised beds with residue retention, as these might have helped to maintain favourable soil moisture, moderate soil temperature and improve soil nutrient status (Amgain et al., 2013; Saad et al., 2015).

The yield attributes of wheat such as number of effective tillers, spike length, number of grains per spike and test weight varied significantly in both years due to different tillage, residue, crop establishment and N management practices. The CA-based practices showed significant improvement in increasing yield attributing characters of wheat (Table 2). Among CA-based practices, the treatments with residue retention were found superior than the residue removal treatments. The plots under PBB+R+100N resulted in significantly higher number of effective tillers, spike length, number of grains per spike and test weight of wheat. The treatment PBB+R+100N led to 12.2% higher test weight of wheat compared to CT. The treatment PBB+R+100N was found comparable with the treatments FB+R+100N, PNB+R+100N and PBB+R+75N in this regard. Results indicated the positive effects of residue retention in improving the yield attributes in wheat cultivation. Similar results were reported by Nath et al. (2015).

Table 2: Yield attributing characters of wheat across treatments

	No. of effective tillers (1 m row length)	Spike length (cm)	No. of grains spike^{-1}	Test weight (g)
CT	90.0	11.5	50.6	39.72
PNB	100.2	12.0	54.5	41.87
PNB+R+75N	109.5	12.4	58.8	43.13
PNB+R+100N	117.7	12.6	61.8	44.16
PBB	105.0	12.0	56.0	42.35
PBB+R+75N	114.8	12.7	61.0	43.53
PBB+R+100N	121.2	12.9	63.0	44.56
FB	103.5	12.1	54.8	42.10
FB+R+75N	112.5	12.5	59.4	43.30
FB+R+100N	118.7	12.7	61.6	44.38
SEm±	2.9	0.1	0.6	0.35
CD (*p*=0.05)	8.7	0.3	1.7	1.03

Refer materials and methods for treatment details

3.2. *Wheat productivity*

The CA-based practices resulted in 7.2–27.1% higher grain yield and 5.7–20.6% higher straw yield compared to CT (Figure 2 and 3). Significantly higher grain yield was observed in CA-based residue retained treatments than that of residue removal treatments. 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, as evidenced by a greater number of effective tillers m^{-2} row, grains/ear, and test weight (Nath et al., 2015). The treatments PBB+R+100N and FB+R+100N resulted in significantly higher grain yield (6.34 t ha^{-1}) and straw yield (8.91 t ha^{-1}) of wheat, respectively. These treatments were found to be at par with all the CA-based practices with residue. The increased grain yield under the treatment PBB+R+100N might be attributed to favorable mulching effects of crop residues. Residue retention 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 CA-based permanent broad bed with residue retention (Chauhan et al., 2007, Thomas et al., 2007, Das et al., 2018; Baghel et al., 2020; Das et al., 2020). According to Jat et al. (2020), ZT with residue

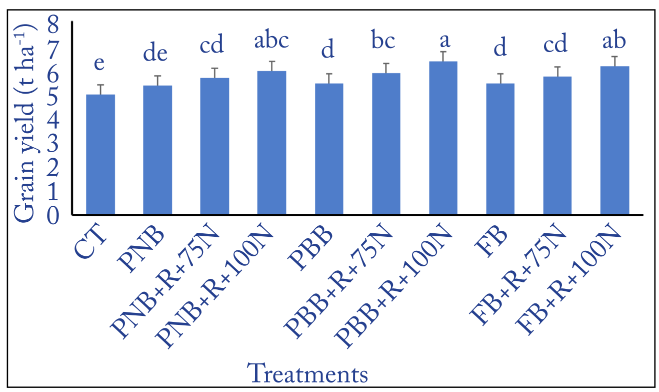

Figure 2: Grain yield of wheat across treatments

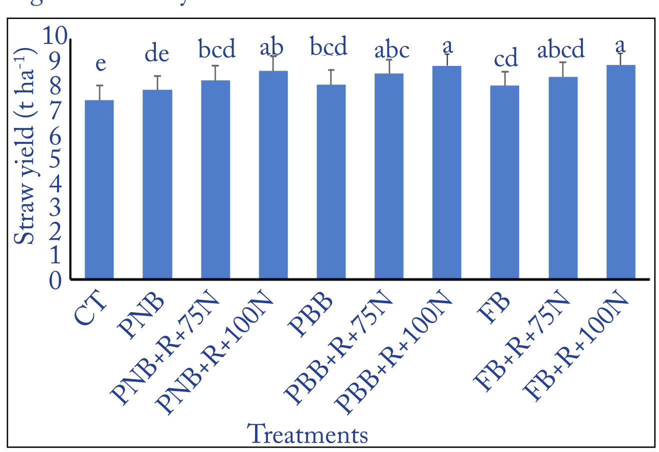

Figure 3: Straw yield of wheat across treatments

retention resulted in 5.8% yield benefit and 25.9% gain in net economic returns in maize-wheat system.

3.3. Nutrient uptake in wheat

The CA-based practices significantly improved nutrients (N, P and K) uptake by both grain and straw in wheat (Table 3). The plots with residue retention had significantly higher nutrient uptake than residue removal plots. Also, the plots under residue retention and 100% N application recorded higher values of nutrient uptake as compared to treatments with 75% N application. Among all the practices, the plots under PBB+R+100N and FB+R+100N registered significantly higher N uptake by wheat grain (120.4 kg ha^{-1}) and straw (27.2 kg ha^{-1}), respectively. The total N uptake by wheat grain and straw (147.4 kg ha^{-1}) was recorded under PBB+R+100N (Table 4). It registered 87.0% increase in total N uptake by wheat grain and straw over CT. The maximum P uptake by wheat grain was recorded under FB+R+100N, while significantly higher P uptake by wheat straw was registered under the treatment PBB+R+100N. Results showed that the treatment PBB+R+100N registered significantly higher uptake of total P (38.4 kg ha^{-1}) by wheat grain and straw and was found to be 67.2% higher compared to CT system. It was found comparable with the treatment FB+R+100N. The treatments PBB+R+100N and FB+R+100N had significantly higher K uptake by wheat grain and straw, respectively. The plots under FB+R+100N registered significantly higher uptake of total K (163.1 kg ha^{-1}) by wheat grain and straw and was found comparable with PBB+R+100N and PNB+R+100N. The treatments PBB+R+100N and FB+R+100N improved K uptake to the tune of 41.6% and 44.1%, respectively over CT. The overall improvement in nutrients uptake by wheat grain and straw was registered under the plots of PBB+R+100N. The increased plant nutrient content in wheat grain and straw under CA might be attributed to improved root growth, which raised nutrient concentration in these crops owing to growing forage area for nutrient removal under permanent beds with residue, resulting in increased nutrient absorption (Parihar et al., 2018).

Table 3: Nutrients (N, P and K) uptake by wheat grain and straw across treatments

Treatments	N uptake by wheat grain (kg ha^{-1})	N uptake by wheat straw (kg ha^{-1})	P uptake by wheat grain (kg ha^{-1})	P uptake by wheat straw (kg ha^{-1})	K uptake by wheat grain (kg ha^{-1})	K uptake by wheat straw (kg ha^{-1})
CT	61.4	17.4	13.2	9.8	13.2	100.0
PNB	87.0	20.1	15.1	11.1	22.1	110.4
PNB+R+75N	101.2	22.0	17.1	12.5	24.3	117.6
PNB+R+100N	111.4	22.7	19.9	14.8	27.6	126.1
PBB	91.4	20.3	15.8	12.3	23.0	116.0
PBB+R+75N	104.1	21.6	17.4	14.6	26.5	123.9
PBB+R+100N	120.4	27.0	22.3	16.1	28.8	131.4
FB	95.7	21.1	15.4	13.5	22.8	118.8
FB+R+75N	101.5	21.7	17.1	13.5	24.5	124.1
FB+R+100N	115.8	27.2	22.4	15.8	28.2	134.9
SEm±	7.8	1.1	1.0	0.6	0.9	3.4
CD (*p*=0.05)	23.2	3.3	3.0	1.9	2.9	10.1

Refer materials and methods for treatment details

Table 4: Total nutrients (N, P and K) uptake by wheat grain and straw across treatments

Treatments	N	P	K
CT	61.4	17.4	13.2
PNB	87.0	20.1	15.1
PNB+R+75N	101.2	22.0	17.1
PNB+R+100N	111.4	22.7	19.9
PBB	91.4	20.3	15.8
PBB+R+75N	104.1	21.6	17.4
PBB+R+100N	120.4	27.0	22.3
FB	95.7	21.1	15.4
FB+R+75N	101.5	21.7	17.1
FB+R+100N	115.8	27.2	22.4
SEm±	7.8	1.1	1.0
CD (*p*=0.05)	23.2	3.3	3.0

N: Total N uptake by wheat grain and straw (kg ha^{-1}); P: Total P uptake by wheat grain and straw (kg ha^{-1}); K: Total K uptake by wheat grain and straw (kg ha^{-1}); Refer materials and methods for treatment details

3.4. *Economics of wheat cultivation*

The cost of cultivation in wheat varied significantly in different treatments due to various costs involved in tillage, residue and crop establishment practices. The CA-based residue retained practices incurred higher cost of cultivation than other practices due to costs involved in residue application. Although the cost of cultivation was marginally higher in treatments with residue retention, these treatments registered higher net returns and net benefit: cost ratio and were proved to be superior to other practices. The CA-based practices with residue retention with 100% N registered 9.7% higher cost of cultivation, but resulted in 24.3–35.1% higher net returns than CT (Table 5). Higher cost of cultivation/land preparation and lower yield of wheat resulted in lower net returns in CT plots (Baghel et al., 2020). Significantly higher gross and net returns were registered under the plots of PBB+R+100N. It resulted in 35.1% higher net returns than that of CT. Higher yield obtained under this practice compensated for the cost of residue retention, resulting in higher net returns.

Table 5: Wheat economics across treatments

Treatments	Cost of cultivation ($\times 10^3$ ₹ ha^{-1})	Gross returns ($\times 10^3$ ₹ ha^{-1})	Net returns ($\times 10^3$ ₹ ha^{-1})	Net benefit: cost
CT	41.13	112.44	71.31	1.73
PNB	37.13	120.22	83.09	2.24
PNB+R+75N	44.62	127.06	82.45	1.85
PNB+R+100N	45.13	133.77	88.64	1.96
PBB	37.13	122.58	85.45	2.30
PBB+R+75N	44.62	131.70	87.08	1.95
PBB+R+100N	45.13	141.48	96.35	2.13
FB	37.13	122.64	85.51	2.30
FB+R+75N	44.62	128.94	84.32	1.89
FB+R+100N	45.13	137.95	92.82	2.06
SEm±	-	2.52	2.52	0.06
CD (p=0.05)	-	7.47	7.47	0.18

1 US$= 69.412 INR and 76.234 INR during 2019 and 2020; Refer materials and methods for treatment details

4. CONCLUSION

Conservation agriculture–based permanent broad bed with residue retention with 100% N (PBB+R+100N) resulted in significant improvements in crop growth, productivity, nutrient uptake as well as profitability in wheat under the maize–wheat–mungbean system. It may be recommended for sustainable wheat production in north–western Indo–Gangetic Plains of India under the maize-wheat-mungbean sequence.

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