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Nitrogen dose and placement in conservation agriculture for augmenting crop growth, productivity and profitability of Indian mustard (*Brassica juncea*)

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ABSTRACT

Optimization of nitrogen (N) fertilization is vital for minimizing losses and realizing the yield potential of Indian mustard [*Brassica juncea* (L.) Czern.] under different tillage and residue management options. Hence, a field experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of nitrogen placement methods under conservation agriculture (CA) for augmenting crop growth, productivity and profitability of Indian mustard. Experiment consisted a split-plot design with three crop establishment practices (CEP) [ZT-R, Zero tillage without residue retention; ZT+R, Zero tillage with residue; CT, Conventional tillage] in main-plots and nitrogen placement methods (NPM) [control (no N); recommended dose of N (RDN)-conventional; RDN-SSB (subsurface band placement of second N split along the crop rows); 80% RDN-SSB] in sub-plots. The ZT+R enhanced crop growth rate by 6.0–36.1% over CT at various crop stages. The ZT+R reported higher soil moisture by 9–20.7% over CT and ZT-R. Significantly superior seed yield (14.3–28.5%), net return (20.5–53.9%) and benefit cost ratio (21.8–79.0%) was obtained with ZT+R over ZT-R and CT while RDN-SSB recorded 7.3–9.1% higher seed yield over other treatments. Statistically at par results were obtained under RDN-conventional and 80% RDN-SSB for yield attributing characters and seed yield delineating that a saving of 20% N in mustard production is possible without compromising yield and this can reduce environmental footprint as well. Therefore, this study concluded that the residue retention under ZT along with subsurface N placement in mustard crop gives better vegetative growth, yield attributes and yield with a potential to save 20% N and can be opted in semi-arid Indo-Gangetic plains and similar agro-ecologies.

Keywords: Conservation agriculture, Crop growth rate, Maize-mustard-mungbean system, Production efficiency, Sub-surface band placement

Indian Mustard [*Brassica juncea* (L.) Czern.] is grown under diverse agro-climatic conditions mainly in resource constraint conditions ranging from north-eastern/ north western hills to down south under irrigated/rainfed conditions in India. The area and production of mustard is constantly increasing with present scenario of 9.53 mt of production with acreage of 6.56 mha and yield of 1455 kg/ ha during 2021–22 (DACNET 2023). The maize-mustard-mungbean cropping system has shown promise in boosting mustard productivity in the Indo-Gangetic plains (Jat *et al.* 2019) and looking at its tremendous potential, recently, the system has been enlisted into the national crop plan by Government of India. India produces over 700 mt of crop residue annually with cereals sharing 386 mt with a surplus of 50 mt wasted through crop residue burning (Devi *et al.* 2017, Radheshyam *et al.* 2023). The surplus residue could be utilized scientifically by adopting conservation agriculture (CA) practices. CA practices have emerged as a transformative approach to sustainably enhancing crop growth and productivity while promoting environmental conservation. Among the various crops, mustard holds significant importance due to its nutritional and economic value, making it a prime target for research in CA practices.

Nitrogen (N) as a key constituent of plant proteins, enzymes, and chlorophyll, directly affects plant growth, development, and overall yield potential towards improving crop productivity (Ladha *et al.* 2022). However, the partial factor productivity of nitrogen (PFP_N) is steadily decreasing owing to improper and unscientific management practises (Padhan *et al.* 2021), which can lead to environmental pollution, economic losses, and suboptimal crop performance. The traditional broadcast application of nitrogen fertilizer often results in significant nutrient losses through volatilization, leaching, and runoff, resulting in environmental degradation and economic inefficiency

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(Chivenge *et al.* 2021). In contrast, Sub-surface Band Placement (SSB) involves placing N in proximity to the crop's root zone, ensuring targeted and efficient nutrient uptake (Ma *et al.* 2023). The fertilizer N placement specially the second split could help in enhancing the nitrogen use efficiency (NUE) of crops under CA (Nayak *et al.* 2022). Therefore, innovative nitrogen fertilization techniques must be explored to maximize NUE and minimize nitrogen losses in CA perspectives for bridging the potential yield gaps.

To date, research is scarce on the combined impact of CA practices and nitrogen placement methods specifically in the context of mustard cultivation. Therefore, a study was carried out to assess the effect of nitrogen placement methods under CA to bridge this knowledge gap and provide comprehensive insights into the potential synergistic effects of these practices on mustard crop growth and yield.

MATERIALS AND METHODS

Field experiments were conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The soil had a sandy loam texture with a slight alkaline *p*H of 7.6, 0.41% organic carbon, low available nitrogen (246 kg/ha), medium phosphorus availability (15.4 kg/ha), and high available potassium (244.2 kg/ha). The experiment was conducted in a 8 year old conservation agriculture trial in maize-mustard-mungbean cropping system. The experiment was set up in a split plot design with crop establishment practices (CEP) [ZT+R, Zero tillage with residue retention; ZT-R, Zero tillage without residue; CT, Conventional tillage] in main-plots and nitrogen placement methods (NPM) [Control (only P and K); Recommended Dose of N (RDN)-conventional: 50% N basal band placement + 50% N surface application along crop rows (at 40–45 DAS); RDN-SSB, 50% N basal band placement + 50% N sub-surface band (SSB) placement along crop rows at 40–45 DAS; 80% RDN-SSB, 40% N basal band placement + 40% N SSB placement at 40–45 DAS] in sub-plots and replicated thrice. The RDN was 90 kg N/ha (Urea and DAP as source) with 40 and 30 kg of P_2O_5 and K_2O, respectively. Mustard (cv. Pusa Mustard-31) was grown at a 45 cm × 10 cm spacing. Mungbean residues were applied @1.5 t/ha in all residue-added treatments before sowing of kharif maize in first year of establishment (2012). For subsequent cropping seasons, approximately 40 cm height of maize stover as residues, stubbles of mustard and 100% mungbean residue were returned in ZT+R. Normal pattern of weather for temperature and rainfall was seen during both the year of study. Three irrigations have been administered to augment the effective rainfall. Five plants per plot were tagged for data collection on growth metrics and yield component estimation. Destructive samples were taken for dry matter estimation while SPAD value of five tagged plant was measured using SPAD-502 chlorophyll meter. The net plot (39.56 m^2) seed yield was recorded and reported at 8% moisture content. The production efficiency (kg/ha/day) was obtained by dividing the grain yield with the crop duration. The analysis of variance was used to performed the statistical analysis and the least significant differences (LSD) was used to compare the treatment means at 5% confidence level. Bartlett test of variance was executed to determine the homogeneity of error variances across the years followed by pooled analysis of two years. The box plots and correlation panel graph were drawn using the ggplot2 package of R-software version 4.3.1.

RESULTS AND DISCUSSION

Growth parameters of mustard: Significantly higher plant height was recorded by ZT+R over CT and ZT-R by 8.5 and 3.4% at harvest, respectively (Table 1). Among the NPM, RDN-SSB recorded significantly higher plant height at all stages whereas RDN-conventional and 80% RDN-SSB were statistically at par. ZT+R recorded significantly higher dry matter accumulation (DMA) by 11.1–14% compared to ZT-R. This might be due to the residue retention effect of previous as well as present crop might have provided a congenial crop growth condition (Devi *et al.* 2017, Parihar *et al.* 2017). Similarly, RDN-SSB had significantly higher DMA over RDN-conventional by 17.3–19.3% at different crop growth stages. The 80% RDN-SSB exhibited significantly better DMA compared to RDN-conventional at 90 DAS and harvest. Similarly, the LAI was found to be significantly superior in ZT+R by 5.1 and 8.5% over ZT-R and 5.7 and 15.9% over CT at 60 and 90 DAS, respectively. Whereas, the N placement methods didn't influence the LAI significantly in both the stages. This might be due to the residue retention in CA significantly enhances the LAI of mustard by providing a protective layer against water evaporation and promoting higher photosynthetic efficiency and biomass production (Kadam *et al.* 2022). Significantly higher SPAD values were obtained in ZT+R over CT which were statistically at par with ZT-R. The N placement methods didn't affect the SPAD value significantly but SSB of N might leads to better N availability and uptake by the crop which reflected in crop greenness and in turn better SPAD value in RDN-SSB. The crop growth rate (CGR) was increased gradually from initial growth stages and reflected higher growth rate between 30–60 DAS and followed a decreased trend towards maturity. ZT+R reported significantly improved CGR by 2.0–15.6% compared to ZT-R and by 6.0–36.1% higher over CT at 0–30, 30–60 and 60–90 DAS. As elucidated by Amgain and Sharma (2013), the higher nutrient availability and ideal moisture under residue mulching led to increased CGR in ZT+R. In early crop stage, the RDN-SSB was statistically at par with RDN-conventional but at the subsequent stages RDN-SSB had significantly better CGR as the subsurface N placement might have led to prolonged availability to the crop. Similar results were also obtained by Kadam *et al.* (2022).

Soil moisture: ZT+R recorded significantly higher soil moisture content at 0–15 cm depth by 9.0 and 20.7% over ZT-R and CT, respectively. In the 15–30 cm soil layer, ZT+R recorded significantly higher soil moisture content by 7.6% over CT but found to be statistically at par with ZT-R.

Table 1 Effect of CEP and NPM on the vegetative growth and soil moisture during flowering of mustard (pooled data of two years)

Treatment	Plant height (cm) at harvest	Dry matter (g/plant)		LAI		SPAD value		Crop growth rate ($g/m^2/day$)			Soil moisture at flowering (%)		
		90 DAS	At harvest	60 DAS	90 DAS	30 DAS	60 DAS	0–30 DAS	30–60 DAS	60–90 DAS	0–15 cm	15–30 cm	30–45 cm
Crop establishment practices (CEP)													
ZT+R	164.2	32.71	38.29	2.41	3.47	31.92	39.71	1.72	9.21	5.43	13.38	14.41	16.32
ZT-R	158.7	29.06	33.59	2.29	3.28	30.21	37.86	1.68	8.15	4.69	12.40	13.93	16.13
CT	151.3	26.7	30.2	2.22	3.00	27.66	36.65	1.62	7.74	3.99	11.25	13.21	16.00
SEm±	2.01	0.22	0.26	0.03	0.05	0.60	0.77	0.01	0.11	0.12	0.16	0.13	0.13
LSD (P=0.05)	6.54	0.73	0.85	0.10	0.17	1.97	2.52	0.04	0.35	0.39	0.51	0.41	NS
Nitrogen placement methods (NPM)													
Control	133.9	21.56	24.24	1.95	2.31	25.72	29.03	1.48	6.13	3.17	12.39	13.70	16.10
RDN-conventional	165.2	29.97	34.56	2.37	3.47	31.33	39.97	1.73	8.36	4.90	12.34	13.89	16.13
RDN-SSB	171.9	35.16	41.24	2.50	3.69	32.26	43.2	1.77	10.12	5.68	12.31	13.97	16.20
80% RDN-SSB	161.3	31.26	36.05	2.40	3.53	30.42	40.09	1.72	8.86	5.05	12.33	13.84	16.17
SEm±	1.95	0.17	0.25	0.03	0.04	0.41	0.54	0.02	0.11	0.14	0.15	0.14	0.10
LSD (P=0.05)	5.59	0.49	0.72	0.09	0.11	1.19	1.55	0.05	0.32	0.40	NS	NS	NS
CEP × NPM	NS	0.85	1.24	NS	NS	NS	NS	NS	0.55	NS	NS	NS	NS
Year (Y)													
Year-1	157.1	29.27	33.53	2.29	3.20	29.66	38.08	1.66	8.27	4.70	12.25	13.79	16.12
Year-2	159.1	29.70	34.52	2.32	3.30	30.20	38.06	1.68	8.46	4.70	12.43	13.91	16.17
SEm±	1.64	0.18	0.21	0.03	0.04	0.49	0.63	0.01	0.09	0.10	0.13	0.10	0.10
LSD (P=0.05)	NS	NS	0.69	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × CEP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × NPM	NS	0.69	1.01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × CEP × NPM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

ZT+R, Zero tillage with residue; ZT-R, Zero tillage without residue; CT, Conventional tillage; RDN, Recommended dose of nitrogen; SSB, Subsurface band placement; NS, non-significance at 5% level of significance (P=0.05)

In the deeper soil layer (30–45 cm), different CEP didn't influence the soil moisture significantly. Moreover, the soil moisture in different layers was not affected significantly by various NPM in both the years as well as in their pooled value. This could comparatively attribute to the retention of residue acting as a boundary layer resistance to check moisture evaporation at soil surface with soil temperature moderation improves the soil moisture holding capacity and its availability through increase in soil organic matter under CA (Parihar *et al.* 2019, Radheshyam *et al.* 2023).

Yield attributes of mustard: Significantly higher plant population was reported in ZT-R over CT which was statistically at par with ZT+R. Similarly, RDN-SSB had higher final plant density over RDN-conventional and 80% RDN-SSB by 4.5 and 7.8%, respectively (Table 2). The second year had significantly higher plant stand. The ZT+R recorded significantly higher primary and secondary branches along with higher siliqua/plant, seeds/siliqua and 1000-seed weight over ZT-R and CT. Residue retention encouraged soil moisture preservation along with improving nutrient availability owing to better soil biological activity might have promoted healthy plant growth leading to better yield attributes (Shekhawat *et al.* 2016, Kadam *et al.* 2022). Among the NPM, RDN-SSB had significantly higher yield attributing traits in mustard which might ascribed to the higher and synchronized N availability thorough sub-surface placement as per crop demand leading to better crop growth and vigour. However, RDN-conventional and 80% RDN-SSB had statistically similar yield attributes which indicates that subsurface band placement of nitrogen could help in reduction of fertilizer dose without compromising crop's yield attributes performance. The SSB enables precise placement of N near the root zone, ensuring optimal nutrient uptake by the mustard plants. This targeted delivery promotes vigorous plant growth, leading to improved yield attributes. The SSB along with residue retention also enhances nitrogen-use dynamics due to better availability of residue as substrate for microorganisms resulting in the efficient utilization of available N contributing to enhanced biomass accumulation, increased number of siliquas in the subsequent years (Nayak *et al.* 2022).

Yield and harvest index of mustard: The ZT+R recorded significantly higher seed and stalk yield by 14.3 and 9.1% over ZT-R and 28.5 and 17.3% over CT, respectively

Table 2 Effect of CEP and NPM on the yield attributes, yield and economics of mustard (pooled data of two years)

Treatment	Plant stand at harvest (×10³ / ha)	Primary branches/ plant	Secondary branches/ plant	Siliqua/ plant	Seeds/ siliqua	1000-seed weight	Seed yield (kg/ha)	Stalk yield (kg/ha)	Harvest index (%)	Net returns (×10³ ₹/ ha)	BCR
Crop establishment practices (CEP)											
ZT+R	151.4	3.60	16.65	557.0	17.74	4.97	2451	6321	27.78	98.8	2.90
ZT-R	154.8	3.39	15.48	482.7	16.74	4.73	2144	5796	26.89	82.0	2.38
CT	147.9	3.13	14.88	448.6	16.33	4.57	1908	5390	26.10	64.2	1.62
SEm±	1.56	0.05	0.21	7.4	0.19	0.05	27	71	0.33	1.4	0.04
LSD (P=0.05)	5.09	0.17	0.67	24.0	0.60	0.16	88	233	1.09	4.7	0.13
Nitrogen placement methods (NPM)											
Control	133.0	2.78	11.75	308.5	14.04	4.35	1605	4805	25.09	54.1	1.67
RDN-conventional	156.8	3.55	16.63	543.4	17.54	4.89	2312	6194	27.09	88.9	2.49
RDN-SSB	163.8	3.67	17.81	591.1	18.72	4.94	2480	6335	28.11	97.2	2.67
80% RDN-SSB	151.9	3.48	16.49	541.6	17.44	4.85	2274	6011	27.40	86.4	2.39
SEm±	1.70	0.08	0.23	5.35	0.24	0.07	23	80	0.29	1.2	0.04
LSD (P=0.05)	4.88	0.23	0.67	15.3	0.69	0.20	67	229	0.84	3.5	0.10
CEP × NPM	NS	NS	NS	NS	NS	NS	116	NS	1.45	6.1	0.17
Year (Y)											
Year-1	148.9	3.30	15.65	482.9	16.79	4.72	2134	5912	26.39	76.8	2.25
Year-2	153.8	3.44	15.68	509.4	17.08	4.79	2202	5760	27.46	86.5	2.36
SEm±	1.27	0.04	0.17	6.0	0.15	0.04	22	58	0.27	1.2	0.03
LSD (P=0.05)	4.16	0.14	NS	19.6	NS	NS	NS	NS	0.89	3.8	0.11
Y × CEP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × NPM	NS	NS	NS	21.7	NS	NS	95	NS	NS	5.0	0.14
Y × CEP × NPM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

ZT+R, Zero tillage with residue; ZT-R, Zero tillage without residue; CT, Conventional tillage; RDN, Recommended dose of nitrogen; SSB, Subsurface band placement; NS, non-significance at 5% level of significance (P=0.05).

(Table 2). Among the NPM, RDN-SSB had significantly superior seed yield by 7.3 and 9.1% over RDN-conventional, 80% RDN-SSB, respectively. The increased growth and yield attributes along with superior soil moisture led to enhanced yield of mustard in our study. The SSB enhances nutrient-use dynamics, fostering a symbiotic relationship between soil and mustard plants with increase in nutrient availability promotes vigorous root development and plant growth, leading to improved yield and productivity (Rathke *et al.* 2006). Grain yield revealed significantly positive correlation with dry matter (R^2=0.767), CGR (R^2=0.719), soil moisture at 0–15 cm (R^2=0.564), number of siliqua/plant (R^2=0.761), net return (R^2=0.983) (Fig 1) which further supports this assumption.

The seed and stalk yield of RDN-conventional was statistically at par with the 80% RDN-SSB which signifies the saving of 20% N can be obtained with at par yield. A significant interaction for seed yield was obtained for CEP × NPM during both the years and ZT+R-RDN-SSB had the highest seed yield (2696 kg/ha) which is significantly higher by 82% over CT with control (Fig 2). The result obtained corroborates with the earlier findings of Jat *et al.* (2019) and Kadam *et al.* (2022). The year × NPM effect was also significant for seed yield where RDN-SSB in the 2nd year reported 6.8% higher seed yield over the 1st year. The harvest index was significantly higher with ZT+R over CT due to superior grain yield in the ZT+R. However, Insignificant effect was observed for the NPM in harvest index.

As a result of the significantly superior growth and productivity, ZT+R recorded significantly higher net return and benefit cost ratio (BCR) by 20.5 and 21.8% over ZT-R and by 53.9 and 79.0% over CT, respectively. However, RDN-SSB obtained a significantly higher net return and BCR by 9.3 and 7.2% over RDN-conventional, by 9.0, 12.5 and 11.7% over 80% RDN-SSB with 54.3, 79.7 and 59.9% over control, respectively. Net return and BCR of 80% RDN-SSB was found to be at par to that of RDN-conventional. The highest production efficiency (PE) (20.3 kg/ha/day) was obtained by ZT+R with RDN-SSB which is significantly higher by 80.7% over CT with control, respectively (Fig 3). As production efficiency is a function of economic yield, this increase was might be due to the higher seed yield of the ZT+R with RDN-SSB over others. These results were in parallel to the findings of Kadam *et al.* (2022).

Inadequate and/or inappropriate N fertilizer management practices can lower crop yields *viz-a-viz* can play a substantial role in use of non-renewable energy for crop production. The study concluded that a combination of subsurface placement of N fertilizer along the side of crop rows in mustard with residue retention had vigorous

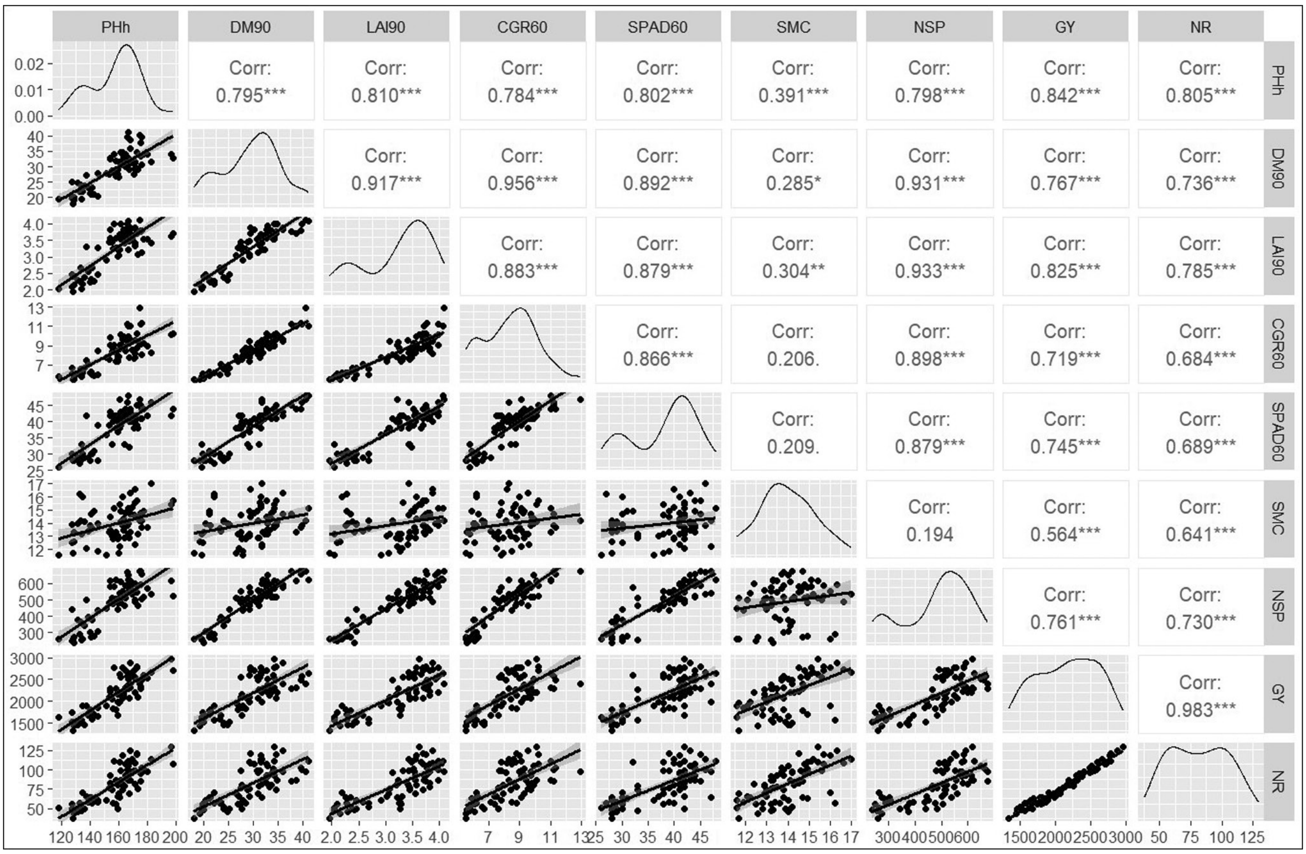

Fig 1 Correlation panel graph between different parameters of mustard (N=72).
PHh, plant height at harvest; DM90, dry matter at 90 days after sowing (DAS); LAI90, leaf area index at 90 DAS; CGR60, crop growth rate at 30–60 DAS; SPAD60, spad value at 60 DAS; SMC, soil moisture content in 0–15 cm soil; NSP, number of siliqua/plant; GY, Seed yield; NR, net return, Significance level: *0.05, **0.01, ***0.001.

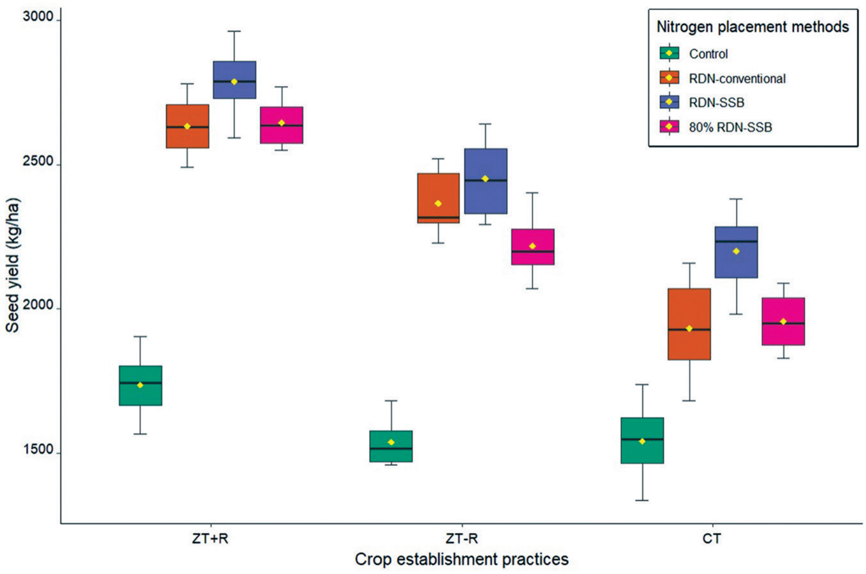

Fig 2 Seed yield of mustard as affected by interaction between crop establishment practices and nitrogen placement methods (pooled data of two years).

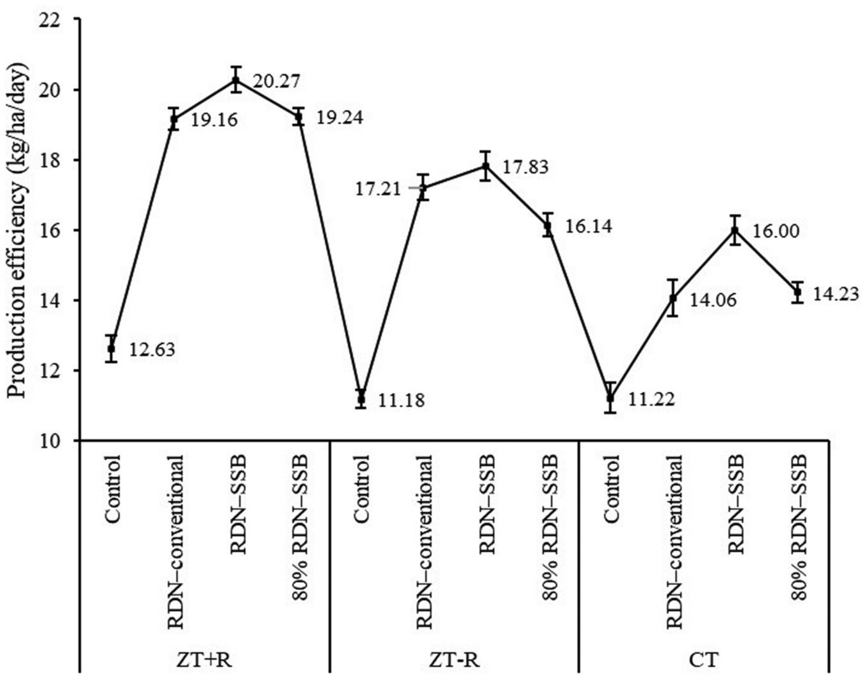

Fig 3 Production efficiency of mustard (pooled) as influenced by combination of CEP and NPM.

vegetative growth, higher yield attributes and mustard yield. It was also concluded that 80% RDN-SSB gave statistically similar yield with the RDN-conventional which has 20% N saving potential without sacrificing the desired yield level. Therefore, subsurface band placement of N along with residue retention in mustard can be recommended for mustard cultivation in Indo-Gangetic plain of India and similar agro-ecological conditions.

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