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RESEARCH ARTICLE

Influence of tillage, residue and nitrogen placement on maize growth and yield under conservation agriculture

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Abstract

Conservation agriculture (CA) is changing the paradigm in production and productivity of maize-wheat system, but proper residue management and quantification, and application of nitrogen (N) are the main bottlenecks. In this context a field experiment was conducted in split plot design consisting of three crop establishment practices (CEPs) in main plots i.e., ZT with residue retention (ZT + R), zero tillage (ZT), conventional tillage (CT) and 4 N placement methods (NPMs) i.e., Control (only P and K applied), RDN: Recommended Dose of N (Band placement of 1/3rd N at sowing followed by surface placement of 1/3rd N during each at V_6 (emerged six leaves with the complete collar visible) and tasselling stage, improved RDN (band placement of 1/3rd N as basal dose followed by 1/3rd nitrogen as subsurface placement at V_6 stage followed by 1/3rd nitrogen as surface band placement at tasselling stage) and improved 80 % RDN (Band placement of 30 % N as basal followed by subsurface placement of 30 % N in maize (at V_6 stage) and surface band placement of 20 % N in maize (at tasselling stage). The ZT + R treatment resulted in significantly higher plant height (6.61-7.02 %) and dry matter accumulation (DMA) (7.50-7.73 %) during different crop growth stages in maize compared to CT. The NPM involving subsurface placement of N at the V_6 stage, that is, improved RDN, significantly increased plant height (2.37-2.73 %) and DMA (1.85-4.13 %) as compared to RDN during different crop growth stages. Significantly higher NDVI and lower CTD values were reported under ZT+R across crop growth stages over the years. ZT + R in combination with improved RDN resulted in significantly higher stover and biological yield by 10.40 and 10.10 %, respectively, as compared to CT with RDN. The improved 80 % RDN saved 20 % N to achieve the same level of productivity as the RDN, emphasising the role of the subsurface placement of nitrogen. Therefore, residue retention in ZT with improved RDN can enhance maize productivity in the Indo-Gangetic Plain and similar agro-ecologies. This research contributes to bridging the gap in nitrogen management under conservation agriculture.

Keywords

conservation agriculture; growth parameters; maize; nitrogen placement; residue retention; yield attributes; zero tillage

Introduction

Maize (*Zea mays* L.) plays a crucial role in global agriculture by providing essential food, feed and bioenergy resources. The maize-wheat system is extensively utilized in semiarid and subhumid regions worldwide to enhance soil fertility, boost crop yields, and introduce crop diversity (1) Conservation agriculture (CA) emerges as a solution to India's agricultural challenges by tackling low farm incomes and deteriorating natural resources, aiming to optimize financial and environmental benefits (2,3). Retaining crop residues is central to CA systems, necessitating advanced crop management practices for in-situ residue management. Challenges in maize-based systems under CA include low nitrogen use efficiency (NUE) due to surface broadcasting and hindrances in surface application caused by residue presence (4). Previous research has emphasised the significant impact of tillage and nitrogen placement methods on maize growth and yield within the maize-wheat system. ZT enhances soil structure, water conservation, fertility, microbial parameters, and crop productivity, whereas effective nitrogen application strategies optimise nitrogen availability to synchronise with crop growth stages and improve NUE. Conversely, CT can induce soil erosion, reduce fertility, and reduce maize yields. Broadcasting nitrogen leads to uneven distribution, increased nitrogen loss, and reduced maize yields. Notably, root density near the soil surface under CA is higher than that under CT-based agriculture, enhancing nitrogen uptake during the initial crop stages (5).

Excessive tillage across crop production systems reduces productivity by consuming substantial energy and disrupting soil processes, thereby affecting soil drying and nutrient loss. Integrating CA practices, such as ZT and residue retention, enhances yield, reduces cultivation costs, and improves soil health (4, 6). This study investigated the impact of diverse CEPs along with various NPMs in residue-rich and residue-less scenarios within a CA-based maize-wheat system established during a long-term ZT field in 2012.

Materials and Methods

The site experiences a subtropical semi-arid climate, and the rainfall received during the research trial was 780 and 580 mm during respective years. The experimental soil was sandy clay loam. The study was conducted in a split-plot design with three crop establishment practices (CEP): zero tillage with residue retention (ZT+R), zero tillage (ZT), conventional tillage (CT) in the main plots, and four nitrogen placement methods (NPM): control, recommended dose of N (RDN), Improved RDN, Improved 80 % RDN in subplots. The residue retained in the ZT +R treatment was mungbean after the pods were picked up during both years. After chemical desiccation of the residues, 100 % of the residues were retained in ZT+R. An average of 2254 and 2272 kg/ha of mungbean residues were retained in 2022 and 2023 respectively. In the control treatment, only P and K were applied at the time of sowing, after which no P or K was applied. RDN practices included the application of 1/3rd N as band placement as basal dose followed by application of 1/3rd nitrogen along crop rows as surface placement, each at the V_6 stage (six leaves with the complete collar visible) and tasselling stage. Improved RDN consisted of application of 1/3rd N as the basal dose, followed by subsurface placement of 1/3rd RDN along crop rows in maize (at V_6 stage), followed by another band placement of 1/3rd RDN in maize (at the tasselling stage). The improved 80 % RDN treatment consisted of band placement of 30 % N as basal followed by the subsurface placement of 30 % N along crop rows in maize (at V_6 stage) followed by another band placement of 20 % N in maize (at tasselling stage). Plant growth parameters such as plant height, dry matter accumulation, and leaf area index were assessed 30, 60 and 90 days after sowing (DAS). Dry matter content was calculated by oven-drying plant samples to a constant weight. Yield indicators, including cob characteristics, grain attributes, and harvest-related metrics, were documented at harvest. Grain yield was obtained from the net plot (39.6 m^2) and reported per hectare at 14 % moisture content. The harvest index and shelling percentage were computed using standard formulas applied to the gathered field data. Grain yield was extrapolated per hectare post-shelling and sun-drying. NDVI values were measured using Green Seeker. A correlation matrix was constructed to determine the relationship between the different parameters and yield. Statistical analysis was conducted using analysis of variance, and the treatment means were compared at a 5 % confidence level using the least significant difference (LSD). The homogeneity of error variances across the years was assessed using the Bartlett test of variance, followed by a pooled analysis of the two years, the results of which are presented. The "ggplot2" package of R software version 4.3.1 was used to draw the box plots and correlation panel graph.

Results and Discussion

Crop growth parameters

The ZT + R and subsurface band-placed nitrogen management techniques (improved RDN, improved 80 % RDN) had superior growth parameters compared to CT and other NPMs. The ZT + R consistently had significantly taller plants across all growth stages, demonstrating its superiority (Table 1). The CT plots displayed lower plant heights, ranging from 6.20 to 6.56 %, compared with the ZT + R treatments at various maize growth stages. Enhanced plant height was also observed with improved RDN, showcasing a 2.37–2.73 % increase in height compared to RDN across different growth phases. The use of the improved RDN initially was at par with the RDN performance, but surpassed them in later growth stages, showing the superior efficiency of subsurface nitrogen placement at the V_6 stage over conventional fertilisation approaches. The subsurface point placement of the N split may have led to an advanced peak growth rate in ZT + R (5). The significant interaction effect between CEP and NPMs was evident at 90 days after sowing (DAS), with the ZT + R combined with improved RDN exhibiting the higher plant height which was equal to 191.93 cm (Fig. 1.). Additionally, the ZT + R showed significantly higher dry matter accumulation (DMA) throughout the crop growth stages than CT by

Table 1. Effect of crop establishment practices and nitrogen placement methods on plant height, dry matter accumulation and leaf area index of maize (pooled mean over 2 years).

Treatments	Plant height (cm)			Dry matter accumulation (g/m^2)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Year (Y)									
2022	55.17^{a}	168.2^{b}	174.3^{a}	206.7^{a}	553.2^{a}	1437.3^{a}	1.62^{a}	5.11^{a}	3.75^{a}
2023	56.16^{a}	170.8^{a}	177.3^{a}	216.8^{a}	557.8^{a}	1453.1^{a}	1.62^{a}	5.22^{a}	3.80^{a}
SEm±	0.47	0.74	0.90	0.90	4.58	8.32	0.005	0.025	0.007
LSD (p =0.05)	NS	2.41	1.10	2.94	NS	NS	NS	0.08	0.02
Crop Establishment Practices (CEP)									
ZT+R	56.5^{a}	175.2^{a}	180.6^{a}	213.1^{a}	576.5^{a}	1511.3^{a}	1.62^{a}	5.31^{a}	3.88^{a}
ZT	55.9^{a}	169.6^{b}	177.3^{b}	211.1^{a}	555.1^{b}	1453.3^{b}	1.62^{a}	5.19^{b}	3.78^{b}
CT	54.5^{a}	163.7^{c}	169.4^{c}	211.2^{a}	535.1^{c}	1405.8^{c}	1.61^{a}	5.00^{c}	3.67^{c}
SEm±	0.58	0.91	1.10	1.10	5.61	10.32	0.006	0.03	0.01
LSD (p= 0.05)	NS	2.95	3.60	NS	18.29	33.67	NS	0.10	0.03
Nitrogen Placement Methods (NPM)									
Control	50.5^{b}	156.4^{c}	160.8^{d}	202.5^{b}	496.4^{c}	1314.2^{c}	1.55^{b}	4.84^{c}	3.59^{c}
RDN	56.8^{a}	172.5^{b}	178.9^{c}	214.2^{a}	565.5^{b}	1495.4^{b}	1.64^{a}	5.21^{b}	3.82^{b}
Improved RDN	58.0^{a}	176.6^{a}	183.8^{a}	213.7^{a}	588.9^{a}	1523.2^{a}	1.65^{a}	5.37^{a}	3.86^{a}
Improved 80% RDN	57.4^{a}	172.5^{ab}	179.7^{b}	216.8^{a}	571.2^{a}	1494.4^{b}	1.63^{a}	5.24^{b}	3.83^{b}
SEm±	0.45	1.44	1.22	1.14	4.96	6.98	0.01	0.02	0.01
LSD (p= 0.05)	1.30	4.12	3.50	3.26	14.23	20.01	0.02	0.06	0.02
CEP × NPM	NS	NS	6.06	5.64	NS	34.65	NS	0.10	0.03
Y × CEP	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × NPM	1.83	NS	NS	4.60	NS	28.29	NS	0.08	0.02
Y × CEP × NPM	NS	NS	8.57	7.97	NS	NS	NS	0.14	NS

ZT+R: Zero tillage with residue, **ZT**: Zero tillage without residue, **CT**: Conventional tillage, **RDN**: recommended dose of nitrogen, **SEm±:** Standard error of mean **LSD**: Least significant difference; **DAS**: days after sowing, **NS**: non-significance at 5% level of significance, similar alphabets within the column signifies non-significance at p=0.05.

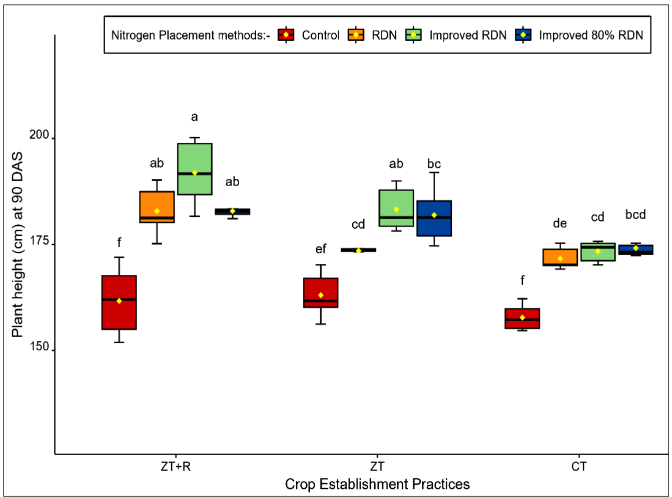

Fig. 1. Interaction effect of crop establishment practices and nitrogen placement methods on the plant height of maize at 90 **DAS** (N=72 for two years), similar alphabets signify non-significance at p=0.05.

7.50-7.73 % during different growth stages. The increase in DMA under ZT +R might be attributed to improved soil health conditions, including enhanced soil aggregate stability, moisture retention, and increased microbial activity, which foster optimal conditions for robust crop growth and establishment (4, 7). The ZT + R had a higher Leaf Area Index (LAI) than CT at 60 and 90 DAS. The ZT + R showed an increase of 6.20 and 5.72 % in LAI over CT at 60 and 90 DAS, respectively. Improved RDN resulted in significantly higher LAI than RDN by 1.05-3.07 % during different crop growth stages of maize.

NDVI (Normalized Difference Vegetation Index)

Significant differences in NDVI values have been reported due to CEPs across stages over the years. The ZT+ R had significantly higher NDVI values than CT at 60 and 90 DAS. RDN had NDVI values at par with the improved 80 % RDN, but significantly higher than the control (Table 2) (8), also found significantly higher chlorophyll a and chlorophyll b contents in maize leaves in the ZT–permanent bed than in the CT across the crop growth stages. This might be because of ZT, along with residue retention, improves the nitrogen and moisture dynamics which ultimately translates into higher chlorophyll concentrations and NDVI values.

CTD (Canopy Temperature Depression)

A noticeable difference was evident in the CTD due to CEPs, with the ZT+R reporting lower CTD than CT at various stages of maize growth. This difference may be attributed to the superior soil properties, water retention capacities, and organic matter content present in the ZT plots compared to CT, which facilitated better crop vigour and adequate moisture inside the plant, leading to higher

Table 2. Effect of crop establishment practices and nitrogen placement methods on the NDVI and CTD of maize (pooled mean over 2 years).

Treatments	NDVI values			CTD values		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Year (Y)						
2022	0.55	0.74	0.60	-1.25	-0.79	-0.29
2023	0.65	0.75	0.66	-1.85	-0.54	-0.63
SEm±	0.05	0.01	0.005	0.30	0.24	0.16
LSD (p=0.05)	0.01	NS	0.02	NS	NS	NS
Crop Establishment Practices (CEP)						
ZT + R	0.62[a]	0.77[a]	0.66[a]	-2.34[b]	-1.41[b]	-0.75[b]
ZT	0.60[a]	0.74[b]	0.62[b]	1.55[ab]	-1.33[b]	-0.75[b]
CT	0.58[a]	0.73[b]	0.61[b]	-0.76[a]	0.75[a]	0.12[a]
SEm±	0.01	0.01	0.01	0.36	0.24	0.20
LSD(p=0.05)	NS	0.02	0.02	1.19	0.77	0.64
Nitrogen Placement Methods (NPM)						
Control	0.54[b]	0.63[b]	0.59[b]	-0.57[a]	-0.19[a]	-0.32[a]
RDN	0.61[a]	0.79[a]	0.65[a]	-1.74[b]	-0.96[b]	-0.66[a]
Improved RDN	0.64[a]	0.80[a]	0.65[a]	-2.02[b]	-0.74[b]	-0.46[a]
Improved 80% RDN	0.62[a]	0.78[a]	0.64[a]	-1.86[b]	-0.75[b]	-0.40[a]
SEm±	0.01	0.01	0.01	0.21	0.16	0.22
LSD (p=0.05)	0.03	0.03	0.02	0.59	0.46	NS
CEP × NPM	NS	NS	0.04	NS	0.80	NS
Y × CEP	NS	NS	0.03	NS	1.09	NS
Y × NPM	NS	NS	NS	NS	NS	0.89
Y × CEP × NPM	NS	NS	NS	NS	1.12	1.55

ZT+R: Zero tillage with residue, **ZT**: Zero tillage without residue, **CT**: Conventional tillage, **RDN**: recommended dose of nitrogen, **SEm±**: Standard error of mean **LSD**: Least significant difference; **DAS**: days after sowing, **NS**: non-significance at 5% level of significance, similar alphabets within the column signifies non-significance at p=0.0.

temperature reduction. For NPMs, no significant difference was observed in CTD between RDN, improved RDN, and improved 80 % RDN; however, the CTD in these groups was significantly lower than that in the control. This discrepancy might be because of N application results in a denser canopy, which leads to more canopy temperature depression than the control resulting in more negative CTD values in the nitrogen applied plots than the control. Residue retention can enhance yield by regulating soil temperature with a favourable CTD in maize and wheat systems (9).

Yield attributes

The ZT + R had significantly higher number of cobs/ha, grains/cob and grain weight/cob by 9.52, 12.45 and 13.27 % respectively than CT. However, no significant difference in cob girth was noticed due to the CEPs. Among NPMs, the improved RDN reported significantly higher grains/cob and grain weight/cob (g) by 3.28 and 2.86 % than RDN, respectively. No significant difference was observed in cob length and cob girth between RDN and improved RDN but improved RDN had 29.53 % higher cob length and 24.27 % higher cob girth than control (Table 3). Subsurface band placement of nitrogen in improved RDN increased the grain weight significantly over the RDN which might be due to the better NUE and nutrient translocation resulting in the superior yield attributes in the improved-RDN (8).

Yield parameters

The ZT+R had statistically significantly higher grain, stover and biological yield than the CT by 8.87, 8.23 and 9.43 %, respectively (Table 4). Among the various NPMs, the improved RDN resulted in statistically significant higher grain and biological yield by 3.40 and 2.92 % respectively, over RDN, but the stover yield was at par with the RDN. (Table 4). Plots using permanent broad beds with and without residue yielded approximately 29 % and 26 % higher maize grain yields respectively, compared to CT (10). Higher grain yields were obtained because of subsurface point placement of both N splits, that is, NPM_3 (involving subsurface band placement) by NPM_2 (involving surface band placement) by 4.7, 7.0 and 6.0 % in CA-based PB, ZT and FZT respectively (5). The interaction effect of CEP and NPMs was not significant for the grain yield, whereas for stover and biological yield the ZT + R in combination with the improved RDN had significantly higher stover and biological yield than CT in combination with the RDN by 10.40 % and 10.10 % respectively (Fig. 2, 3). The ZT+R had increased yields due to increased nutrient availability, soil improvement, moisture retention, and enhanced nitrogen use efficiency (4, 7, 11). The improved RDN enhances crop performance by increasing N availability and minimising losses (8). In addition, correlation analysis revealed that there was a significant positive relation-

Table 3. Effect of crop establishment practices and nitrogen placement methods on yield attributes of maize (pooled mean over 2 years)

Treatments	Cobs ('000/ha)	Cob length (cm)	Cob girth (cm)	Grains/ cob	Grain weight/ cob (g)
Year (Y)					
2022	63.90	16.90	15.83	344.78	89.27
2023	65.04	16.95	15.94	347.31	91.16
SEm±	0.44	0.10	0.11	3.81	1.17
LSD (p=0.05)	NS	NS	NS	NS	NS
Crop establishment practices (CEP)					
ZT + R	67.40[a]	17.47[a]	15.93[a]	367.51[a]	97.88[a]
ZT	64.48[b]	16.67[b]	15.86[a]	343.82[a]	91.34[b]
CT	61.54[b]	16.63[b]	15.86[a]	326.80[b]	86.41[c]
SEm±	0.54	0.12	0.13	4.67	1.44
LSD (p = 0.05)	1.76	0.40	NS	15.22	4.69
Nitrogen management practices (NPM)					
Control	57.43[c]	13.85[b]	13.47[b]	259.60[c]	55.93[c]
RDN	66.87[ab]	18.00[a]	16.63[a]	368.65[b]	102.28[b]
Improved RDN	67.46[a]	17.94[a]	16.74[a]	380.77[a]	105.51[a]
Improved 80% RDN	66.12[b]	17.91[a]	16.68[a]	375.16[b]	103.79[ab]
SEm±	0.38	0.08	0.08	3.37	1.04
LSD (p=0.05)	1.09	0.22	0.22	9.67	2.97
CEP × NPM	NS	0.39	NS	16.74	5.15
Y × CEP	NS	NS	NS	NS	NS
Y × NPM	NS	NS	NS	NS	NS
Y × CEP × NPM	NS	NS	NS	NS	NS

ZT+R: Zero tillage with residue, **ZT**: Zero tillage without residue, **CT**: Conventional tillage, **RDN**: recommended dose of nitrogen, **SEm±**: Standard error of mean **LSD**: Least significant difference; **DAS**: days after sowing, **NS**: non-significance at 5% level of significance, similar alphabets within the column signifies non-significance at p=0.05.

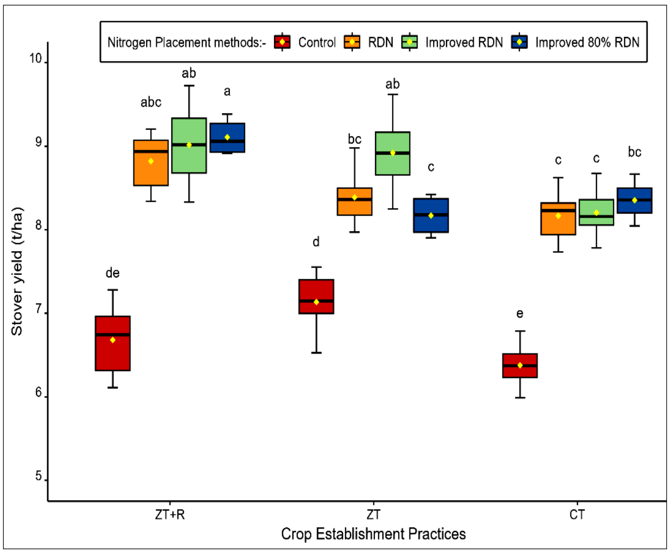

Fig. 2. Interaction effect of crop establishment practices and nitrogen placement methods on the stover yield of maize (**N**=72), similar alphabets signify non-significance at p=0.05.

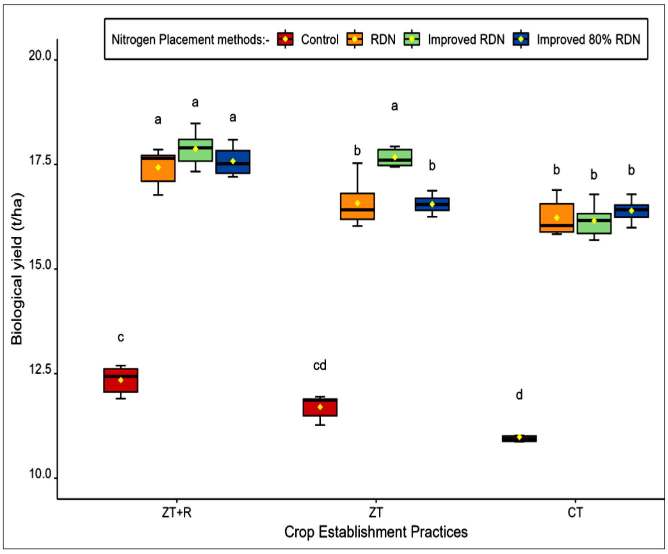

Fig. 3. Interaction effect of crop establishment practices and nitrogen placement methods on the biological yield of maize (**N**=72), similar alphabets signify non-significance at p=0.05.

ship between grain yield and other parameters, viz., plant height (r^2=0.825), LAI (r^2=0.808), dry matter accumulation (r^2=0.848), and grains/cob (r^2=0.944) which corroborates the results of higher grain yield in ZT+R and improved RDN. This is shown in Fig. 4.

Quality attributes

No significant differences were observed among the CEP for harvest index (HI) and shelling per cent. Among the NPMs, HI in the improved RDN was at par with the RDN and improved 80 % RDN which was significantly higher than the control (Table 4). The interaction effect of CEP and NPMs was significant for shelling % where the ZT+R with improved RDN had significantly higher shelling % over CT and ZT with RDN.

Table 4. Effect of tillage and nitrogen placement methods on yield, harvest index and shelling % in maize (pooled mean over 2 years).

Treatments	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Shelling (%)
Year (Y)					
2022	5.74	8.03	15.54	36.35	75.73
2023	5.82	8.20	15.71	36.49	76.98
SEm±	0.03	0.05	0.05	0.20	0.75
LSD (p=0.05)	NS	NS	NS	NS	NS
Crop establishment practices (CEP)					
ZT + R	6.01^{a}	8.41^{a}	16.35^{a}	36.28^{a}	74.97^{a}
ZT	5.81^{b}	8.15^{b}	15.62^{b}	36.55^{a}	77.42^{a}
CT	5.52^{c}	7.77^{c}	14.94^{c}	36.44^{a}	76.67^{a}
SEm±	0.04	0.06	0.07	0.12	0.80
LSD (p=0.05)	0.15	0.20	0.23	NS	NS
Nitrogen management practices (NPM)					
Control	3.42^{c}	6.73^{b}	11.67^{c}	29.31^{b}	69.82^{b}
RDN	6.47^{b}	8.46^{a}	16.74^{b}	38.64^{a}	78.11^{a}
Improved RDN	6.69^{a}	8.71^{a}	17.23^{a}	38.88^{a}	78.65^{a}
Improved 80% RDN	6.54^{b}	8.54^{a}	16.84^{b}	38.86^{a}	78.86^{a}
SEm±	0.05	0.09	0.09	0.41	0.97
LSD (p=0.05)	0.15	0.27	0.27	1.17	2.78
CEP × NPM	NS	0.46	0.47	NS	4.81
Y × CEP	NS	NS	NS	NS	NS
Y × NPM	NS	NS	NS	NS	NS
Y × CEP × NPM	NS	NS	NS	NS	NS

ZT+R: Zero tillage with residue, **ZT**: Zero tillage without residue, **CT**: Conventional tillage, **RDN**: recommended dose of nitrogen, **SEm±**: Standard error of mean **LSD**: Least significant difference; **DAS**: days after sowing, **NS**: non-significance at 5% level of significance, similar alphabets within the column signifies non-significance at p=0.05.

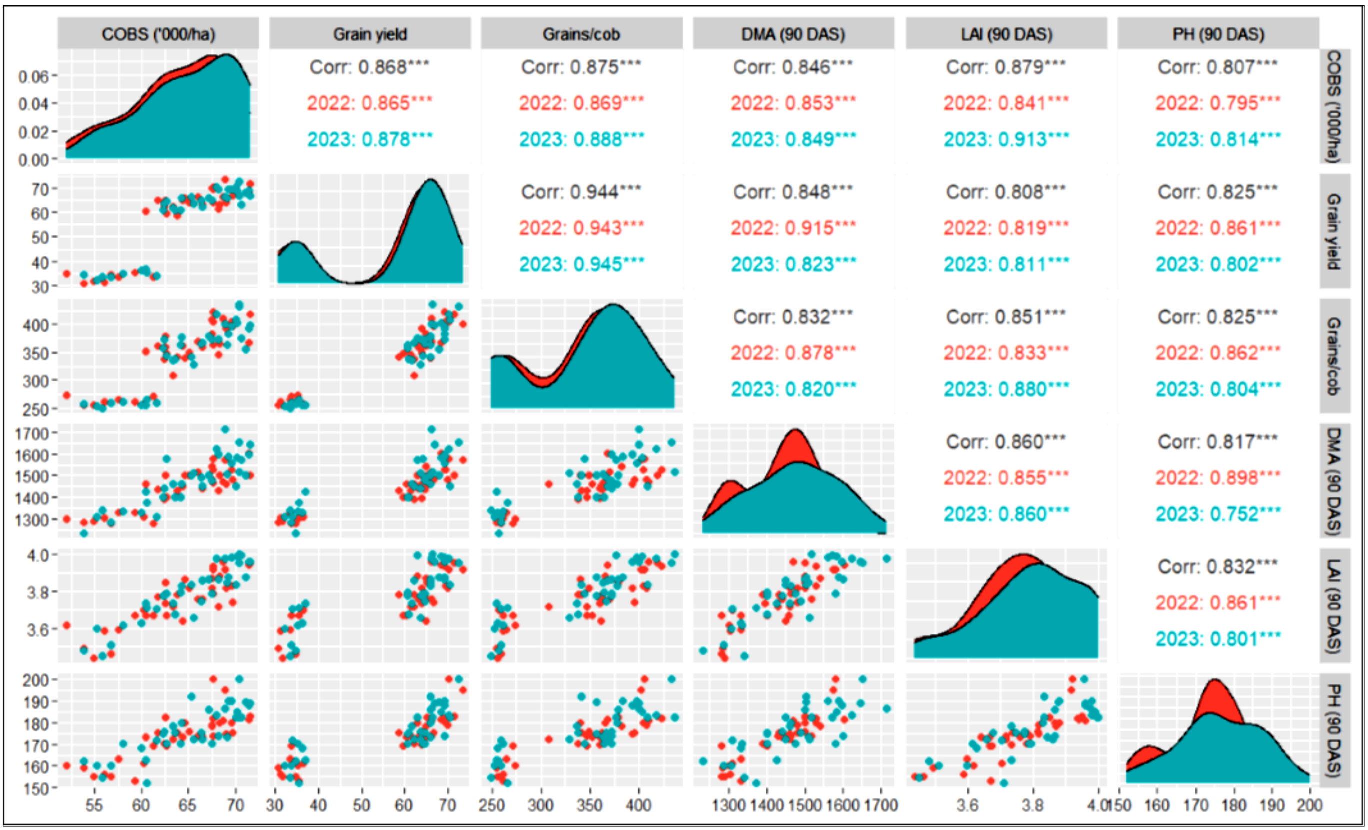

Fig. 4. Correlation panel graph between different parameters (**N**=72), **PH90**: plant height at 90 days after sowing (**DAS**), **LAI90**: leaf area index at 90DAS, **DM90**: dry matter at 90 DAS, Cobs: number of cobs per plant, GPC: grains per cob, GY: Seed yield, Significance level: ***0.001, **0.01, *0.05).

Conclusion

The present study examined the impact of CEP and NPM on maize growth and yield. The ZT + R and ZT outperformed CT in growth attributes leading to higher yield attributes and grain yield. Among the NPMs, significantly higher physical growth attributes, NDVI values, grain yield, and biological yield were reported in the improved RDN signifying saving of 20 % N due to subsurface placement of nitrogen. The improved 80 % RDN had at par or superior results over RDN showing the saving of 20 % N for obtaining similar or superior yield to the conventional fertilization practices. Therefore, residue retention coupled with improved RDN involving subsurface placement of N at V_6 stage can be a better crop management practices for higher growth and crop productivity of maize in maize-wheat rotation under CA.

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Authors' contributions

AG prepared the first draft of manuscript. SLJ designed the whole experiment and treatments. AKS made procedure for taking green seeker and the SPAD readings. CMP compiled the two years data and made sheet to calculate the values on pooled basis. VP made some corrections in the manuscript so that it becomes more lucid. SK also made Grammer corrections and gave idea of correlating different factors. MCM laid out procedure for subsurface band placement of the N. SRP made correlation panel graph in R. AM, MK, RN, AJ helped in taking field readings and smooth flow of operation throughout experiment

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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