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RESEARCH PAPER

Tillage, residue and nitrogen management influences growth attributes, biomass production and yield of maize in the Trans-Gangetic Plains of India

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Abstract A field experiment was conducted during *kharif* season of 2023 at Indian Agricultural Research Institute, New Delhi to investigate the effects of different tillage and residue management practices (TRMs), and nitrogen management practices (NMPs) on the growth, development and yield of maize. Results showed that zero tillage with residue retention (ZT+R) consistently led to superior growth metrics including plant height, dry matter accumulation (DMA), leaf area index (LAI), crop growth rate (CGR), and root parameters by 15-22% higher than conventional tillage (CT). The LAI was the highest under ZT+R, 26.8% greater than CT at 30 DAS. The NMP1 (33% basal N + 33% N as surface placement at 25-30 and 45-50 DAS) initially had the highest plant height and DMA. However, at later crop stages, NMP3 (33% basal N + 42% N as sub-surface band placement 25-30 DAS + 3% urea spray at 45-50 and 60-65 DAS) outperformed with a 36.3% increase in DMA over the control at 90 DAS. Crop growth rate (CGR) and relative growth rate (RGR) were also higher under ZT+R and with NMP3. Root parameters including root density and weight were significantly improved under ZT+R as well as with NMP3. The ZT+R increased grain yield by 31.2% than CT while NMP3 yielded significantly higher yield owing to better root development. It was concluded that combining zero tillage + residue retention with improved nitrogen management practices could be used for enhancing growth and yield of maize in Western Indo-Gangetic plains of India.

Keywords: Biomass production · Growth attributes · Foliar N application · Root parameters · Zero tillage

Introduction

The production of biomass in any crop sequence plays a vital role in determining its sustainability and soil health (Adak *et al.,* 2013). The predominant traditional rice [*Oryza sativa* L.]-wheat [*Triticum aestivum* L.] (R-W) in north-west India which ensuring food security but it has led to issues such as high fertilizer consumption, costly cultivation, excessive irrigation, intensive tillage, energy use, and farm-related pollution (Parihar *et al.,* 2018). These practices have resulted in degraded soil quality with decreased levels of soil organic carbon (SOC) and deficiencies in macro and micronutrients (Ladha *et al.,* 2000). Consequently, poor soil health hinders crop biomass production and reduces the productivity of applied inputs like nutrients and water (Congreves *et al.,* 2015). Declining water availability and negative impacts of climate change, soils with poor physical, chemical, and biological properties are unable to produce sufficient biomass (Congreves *et al.,* 2015). The declining biomass productivity and energy-use efficiency in the RW system

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(Saharawat *et al.,* 2010) raise concerns about its sustainability in meeting future food and energy demands.

Globally, maize (*Zea mays*) is one of the largest cereal crops which cultivated in over 160 countries with increasing popularity due to various industrial uses. As a C_4 crop, maize exhibits better adaptation to climate change, and the introduction of single cross hybrids (SCHs) with high yield potential has made maize cultivation profitable and suitable for carbon trading. Implementing Conservation Agriculture (CA) practices with SCHs maize provides the twin benefits of improving crop productivity and soil health, making it a potential alternative to rice in the RW system of the Indo-Gangetic Plain (Jat *et al*., 2019). The conventional farming systems that extensively till the soil have caused significant erosion and degradation of the soil resource base, particularly when combined with burning crop residues. Excessive tillage involving multiple operations like consumes a substantial amount (25-30%) of the energy used in crop production resulting in decreased productivity across various crop systems (Sidhu *et al.,* 2004). To mitigate these issues, reduced-tillage and no-tillage technologies have been adopted to minimize the costs of tillage and alleviate the negative effects of crop cultivation on the environment. The primary objectives of reduced tillage are to minimize the environmental impact of crop cultivation, protect soil from erosion caused by wind and water, prevent leaching of valuable soil layers, fertilizers and chemicals into water bodies, promote biodiversity, reduce labour and fuel consumption while lower the overall cost of cultivating crops (Feiziene *et al*., 2010).

Effective crop residue management significantly creates an impact the efficiency of applied fertilizers, water, and other inputs in many cropping system (Chauhan *et al*., 2012). To address this, a differential N management strategy should be adopted to account for potential N immobilization or volatilization resulting from residue addition. The non-mixing of residue in long-term ZT system created a residue layer over the soil surface and the higher microbial population was reported in this residue layer (Choudhary *et al*., 2018) which increased the chances of more immobilization, denitrification or leaching of applied nitrogen. Utilizing foliar N application shows promise in enhancing N use efficiency and improving produce quality. The recent introduction of Agri-drones in India offers opportunities for foliar fertilization as a convenient and quick method with a reduced environmental footprint in agricultural production. Application of foliar fertilizers showed an improvement on maize aboveground and underground parts (Balawejder *et al*., 2019). According to Radulov *et al*. (2010), corn fertilization with foliar fertilizers containing nitrogen helps to increase N content. Therefore, integrating tillage, residue management and foliar fertilization can offer dual advantages of increased efficacy and environmental stewardship. To maximize the benefits of in-situ residue retention at the farm level, other efficient crop production technologies can be concurrently promoted. Various practices like conservation tillage, crop diversification/ intensification, residue management, and foliar nutrient spray have been studied individually and reported by researchers, but there is a significant knowledge gap regarding their combined effects. Considering these the study was conducted to observe impact of different tillage and N management practices on the growth attributes, biomass and productivity of maize in Trans-Gangetic plains zone of India.

Materials and methods

The field experiments were performed during the *kharif* season of 2023 at ICAR-Indian Agricultural Research Institute (IARI) farm, New Delhi in developed long term conservation agriculture (CA) based plots started from 2012 which completed almost 10 years. Hence, this experiment was conducted during the 11th cycle, and was located at 28°40' N latitude, 27°11' E longitude and 228 m above mean sea level. This region represents the semi-arid and sub-tropical climate with hot, dry summer (in April and May) and falls within the agro-climatic zone of the Trans-Gangetic plains. The total average rainfall received during the experiment was 178.5 mm [with 108 mm of effective rainfall (ER)] for the *kharif* season, 2023. During the study, the average minimum and maximum temperature was 18.2 and 26.5 °C, respectively. The soil of the experimental field was sandy loam in texture with good drainage and moderate water holding capacity. The soil was neutral in reaction with low in available nitrogen (N) and medium in available phosphorus (P) and available potassium (K). The experiment was laid out in split plot design with three replications. The main-plot consist of tillage and residue management practices (TRMs) *i.e.* zero tillage + residue (ZT+R), zero tillage (ZT) and conventional tillage (CT) while in sub-plots four nitrogen management practices (NPMs) were adopted *viz*., control (without N); NMP1 (Conventional method): 33% basal N + 33% N as surface placement (25-30 and 45-50 DAS); NMP2 (75% RDN + nano urea spray): 33% basal N + 42% N as sub-surface band placement at 25-30 DAS + 4 ml/l nano urea spray at 45-50 and 60-65 DAS) and NPM_3 (75% RDN + urea spray): 33% basal N + 42% N as sub-surface band placement at 25-30 DAS + 3% urea spray at 45-50 and 60-65 DAS). The fertilizer nitrogen (N) in prilled urea was applied as per the treatments and full P and K were applied as basal @ N: P_2O_5: K_2O-150:60:40 kg/ha. Nano-urea was applied @ 4 ml/litre of water and urea at 30 g/l water in the evening as per the treatment. Irrigations were applied by the treatments taking into account the local weather conditions. The variety of maize CP858 was sown in lines with 60 cm ×30 cm spacing using a seed rate of 20 kg/ha on 10th July, 2023. Plant protection measures were taken against insects, weeds and diseases. Periodically growth parameters *viz*., plant height, dry matter accumulation (DMA), leaf area index (LAI), root dry weight were recorded from five representative plants from the continuous row in the centre of the plot. The harvested plant biomass and collected roots were dried in the sun and then dried in an oven at 60°C until they reached a consistent weight which expressed as g/m^2. The collected leaf samples were taken to the lab immediately and the readings were taken with the help of a leaf area meter. LAI was calculated with following mathematical expression (Watson, 1947):

$$\text{LAI} = \frac{\text{Total leaf area per plant (cm}^2\text{)}}{\text{Land area per plant (cm}^2\text{)}}$$

The determination of mean crop growth rate (CGR) was based on recorded dry matter data taken during two subsequent growth stages of maize. This parameter was computed using the formula (Watson, 1952):

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2-W_1}{T_2-T_1}$$

Relative growth rate (RGR) was calculated by means of the ensuing formula (Blackman, 1919):

$$\text{RGR (mg/g dry matter/day)} = \frac{\ln W_2 - \ln W_1}{T_2-T_1}$$

Net assimilation rate (NAR) was estimated with the following given formula (Gregory, 1917):

$$\text{NAR (mg/cm}^2\text{ leaf area/day)} = \frac{W2-W1}{T2-T1}\left(\frac{\ln A2-\ln A1}{A2-A1}\right)$$

Whereas, T_1 = Days at first stage; T_2 = Days at second stage; W_1 = Dry matter accumulation at T_1 (g/m^2); W_2 = Dry matter accumulation at T_2 (g/m^2); A_1 = leaf area at T_1 (cm^2); A_2 = leaf area at T_2 (cm^2).

Data analysis was performed for split-plot design using an online data analysis module using R software. The treatments were compared at a significance level of 5%, the critical difference (CD) and standard error of means (SEm±) for each character were computed.

Results and discussion

Growth attributes

There was a consistent increase in plant height up to 60 DAS, after that the rate of increase in plant height was marginal are presented in Table 1. Plant height was significantly higher in ZT+R by 2.2, 7.3 and 12.5% over to CT at 30, 60 & 90 DAS, respectively and on par with ZT at all stages. In NMPs, the highest plant height was observed under NMP1 which was statistically at par with other NMPs but 19.1% higher than control. After that highest height was observed under NMP3 which was statistically at par with NMP2 and higher than NMP1 by 5.7 & 5.5% at 60 and 90 DAS, respectively. Better availability of N under subsurface banding (SSB) which increased the rate of photosynthesis encouraged the carbohydrate synthesis helped extension of stem resulting in increased chlorophyll content and plant (Saha *et al*., 2023; Mandal *et al*., 2024). Control plot showed the lowest due to the unavailability of sufficient N in the soil that affect the chlorophyll synthesis and metabolic activity of the plant (Kumar *et al*., 2018). Data presented in Table 1 illustrates that the dry matter accumulation (DMA) of maize in different growth stages as affected by different tillage and residue management practices (TRMs) and nitrogen management practices (NMPs). The DMA increased at an increasing rate from 30 DAS followed by 60 and 90 DAS during the study. Zero tillage with residue (ZT+R) resulted highest DMA (~12.5% higher) compared to conventional tillage in all stages. The ZT supplements the crop by providing more nutrients through

Table 1. Effect of tillage and nitrogen management practices on growth attributes at 30, 60 and 90 days after sowing (DAS) of maize

Treatments	Plant height (cm)			Dry matter accumulation (kg/ha)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Tillage and residue management									
ZT + R	48.1	178.5	183.1	239.6	603.7	1356.7	1.75	5.27	4.73
ZT	44.8	175.3	180.4	234.8	585.5	1257.5	1.69	5.07	4.68
CT	37.7	157.8	160.1	224.1	520.9	1187.5	1.28	4.14	3.63
SEm±	2.1	6.2	5.5	7.6	17.9	37.1	0.05	0.12	0.15
LSD (p=0.05)	5.8	12.2	15.2	NS	49.7	93.2	0.13	0.31	0.41
Nitrogen management practices									
Control	37.9	152.4	161.2	185.5	468.9	945.6	1.07	4.10	3.44
NMP1	43.3	172.8	176.2	254.6	574.2	1293.3	1.65	4.97	4.53
NMP2	46.9	173.5	178.3	243.8	603.4	1343.3	1.73	5.07	4.64
NPM3	45.9	183.4	182.4	247.9	633.6	1486.7	1.84	5.17	4.78
SEm±	2.3	5.7	5.3	12.4	22.2	45.9	0.05	0.24	0.19
LSD (p=0.05)	4.8	11.1	11.2	26.1	46.8	96.8	0.10	0.50	0.39

mineralisation by higher microbial growth as well as proper soil moisture retention in the surface soil. Therefore, the plant had increased access to moisture, which led to turgidity in the cells and subsequently enhanced meristematic activity. This resulted in increased photosynthetic activity, more leaf development, and ultimately higher growth and development (Ravisankar *et al*., 2014). Amongst NMPs, the highest DMA was found with 100% RDN at 30 DAS, but at 60 & 90 DAS, it was observed under 75% RDN+2 urea (3%) spray which was almost 36.3 & 13.01% higher compared to control and 100% RDN, respectively. However, lower N management practices led to decreased dry matter accumulation because nitrogen-deficient soil (low in accessible nitrogen) may have impeded cell elongation, which stifled plant vegetative growth (Mandal *et al*., 2024).

Similarly, Leaf area index (LAI) was also affected by both the management practices. The ZT+R practices resulted the highest LAI (26.8% higher than CT at 30 DAS) followed by ZT and CT (Table 1). After 60 DAS, LAI was started fall as the dry leaves are started to fall from the plants without significant addition of new leaves as plan started to drive the energy and nutrition towards the reproductive parts *i.e.* cob and tassel. Among NMPs, the highest LAI was observed in N applied plots which was almost 20% higher than control plot. Nitrogen application accelerated leaf area expansion which led to higher photosynthates being accumulated and higher dry matter production. According to Man *et al*. (2017), the LAI significantly increase which results in the incensement of biomass production.

Crop growth rate (CGR)

The crop growth rate (CGR) increased at an increasing rate from 0-30 DAS followed by 30-60 DAS and 60-90 DAS are given in Figure 1. The different TRMs significantly influenced the CGR at all the crop growth stages. The graph revealed that the ZT+R recorded a superior CGR of 8.0, 12.14, 24.88 g/m^2/day which was significantly at par to ZT-R which in turn recorded significantly higher CGR by 7.5, 18.5 and 14.4% over CT at 0-30, 30 60 and 60-90 DAS, respectively. Among NMPs, the highest CGR was seen in NMP1 which was 27.06% higher at 30 DAS while NMP3 was higher by ~26% at 60 and 90 DAS than control (Figure 1).

The data on relative growth rate (RGR) revealed the higher relative growth at 30-60 DAS with a decreasing trend in the later stages crop growth viz., 60-90 DAS (Table 2). Highest RGR (30.87 mg/g/day) was observed at 30 DAS under ZT+R plot was 8.7% higher than CT. This might be due to the interaction of all the favourable condition and conducive environment provided by the residue retention that underscores a synergistic suite of benefits that collectively amplifies crop growth trajectories within conservation agriculture-based agroecosystems (Jakhar *et al*., 2018; Francaviglia *et al*., 2023). Whereas

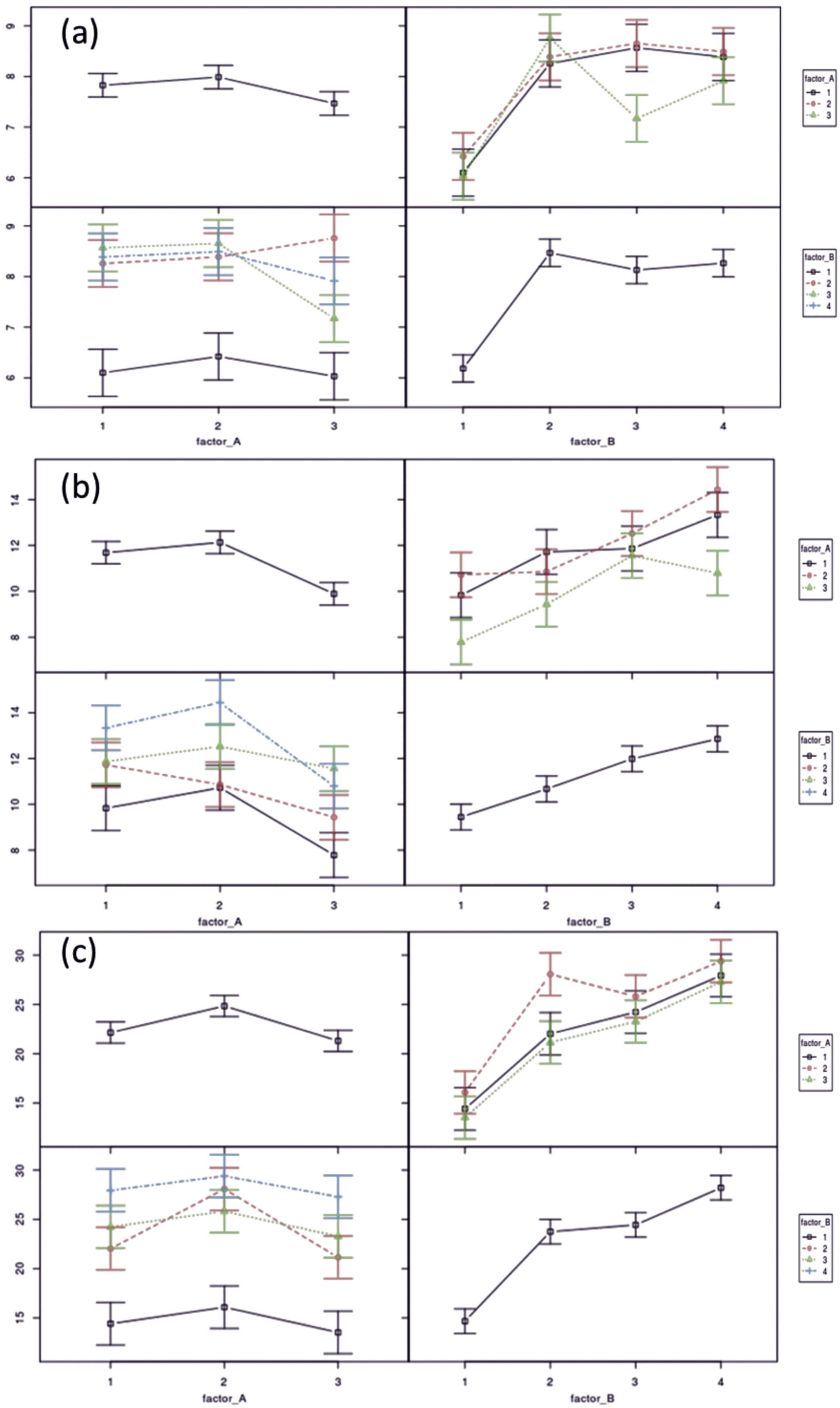

Figure 1. Interaction effect of tillage, residue management, and nitrogen management practices on CGR of maize at different stages i.e. 0-30 days after sowing (a); 30-60 DAS (b) and 60-90 DAS (c).

non-significant difference was observed under NMPs at 30 DAS but highest RGR was observed under NMP1 which was 18.2% higher than control but significantly similar with the other NMPs. Data on net assimilation rate (NAR) revealed non-significant difference due to TRMs practices but in NMPs control plot showed the lowest rate of net assimilation (0.39 mg/cm^2/day), whereas 75% RDN as subsurface placement and 2 urea (3%) spray at 45 and 60 DAS provided 13.5% higher NAR than 100% RDN at 60 DAS (Table 2).

Root parameters

The root fractions were significantly influenced by tillage and residue management (TRMs) practices (Figure 2). However, zero tillage with residue (ZT+R) resulted higher root density, root fresh weight, root dry weight which are statistically at par with ZT but significantly higher than CT practices. In CT, root length was 7.05% higher than ZT whereas root density was highest under ZT+R

Table 2. Effect of tillage, residue and nitrogen management practices on growth indices at 30-60 and 60-90 days after sowing (DAS) of maize

Treatments	Relative Growth Rate (RGR)		Net Assimilation Rate (NAR)	
	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS
Tillage and residue management				
ZT + R	30.87	26.53	0.38	0.45
ZT	30.67	24.93	0.38	0.49
CT	28.18	26.30	0.41	0.54
SEm±	1.77	1.56	0.02	0.03
LSD(p=0.05)	NS	NS	NS	NS
Nitrogen management practices				
Control	30.86	21.94	0.42	0.39
NMP1	27.20	26.82	0.35	0.49
NMP2	30.36	26.51	0.41	0.52
NPM3	31.21	26.42	0.40	0.57
SEm±	2.11	1.89	0.03	0.04
LSD(p=0.05)	NS	3.97	NS	0.08

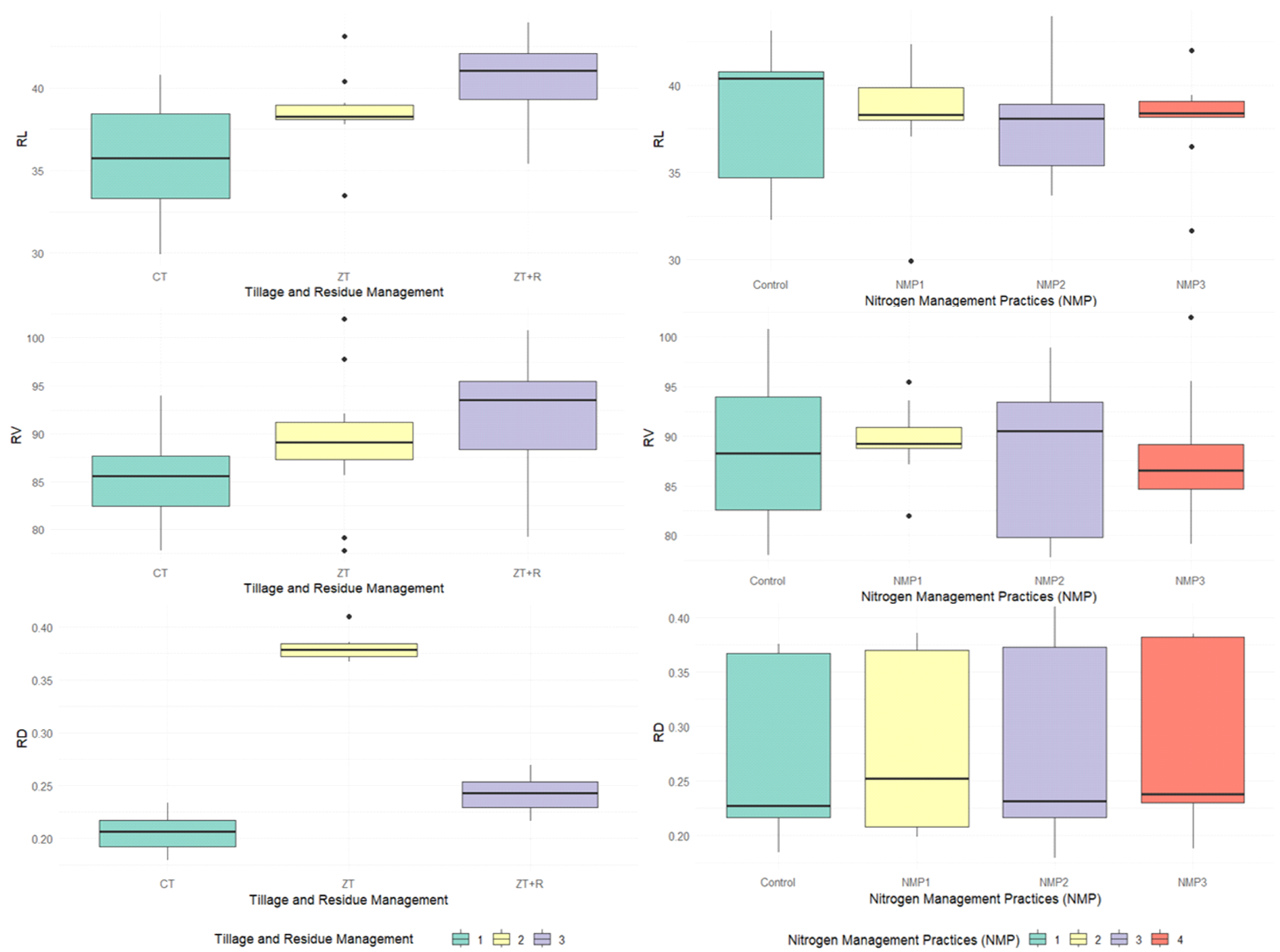

Figure 2. Effect of tillage and nitrogen management practices on root length (RL), root volume (RV) and root density (RD) of maize

by 44.7% higher than CT practices. Investigations elsewhere have indicated that roots elongate more slowly at first under ZT than with CT, whereas lateral branching generally starts earlier which resulting in a dense root system in undisturbed soil under ZT (Choudhary *et al*., 2013). In ZT+R plot, residues are placed in soil helps to check the moisture and make the soil more porous by adding organic matter that helps the root to spread easily. Also the nutrient stratification was observed under ZT+R plot so that the roots are concentrated near the surface of the soil. Root fresh weight as well as root dry weight follows the same trend during the study. Highest root fresh and dry and weight (140.95 and 21.00 g/plant) was observed under ZT+R plots. Among different nitrogen management practices (NMPs), all the root parameters showed non-significant differences (Figure 2).

Grain yield

The highest grain yield was obtained under ZT+R which was 31.16% higher than CT whereas it was also highest in 75% RDN + as subsurface placement and two urea (3%) spray at 45 and 60 DAS among the NMPs are presented in Figure 3. Subsurface placement of fertilizer maintained high levels of nutrients in plant-available form close to the roots, which stimulated root growth close to and away from fertilizer depots, which might be due to

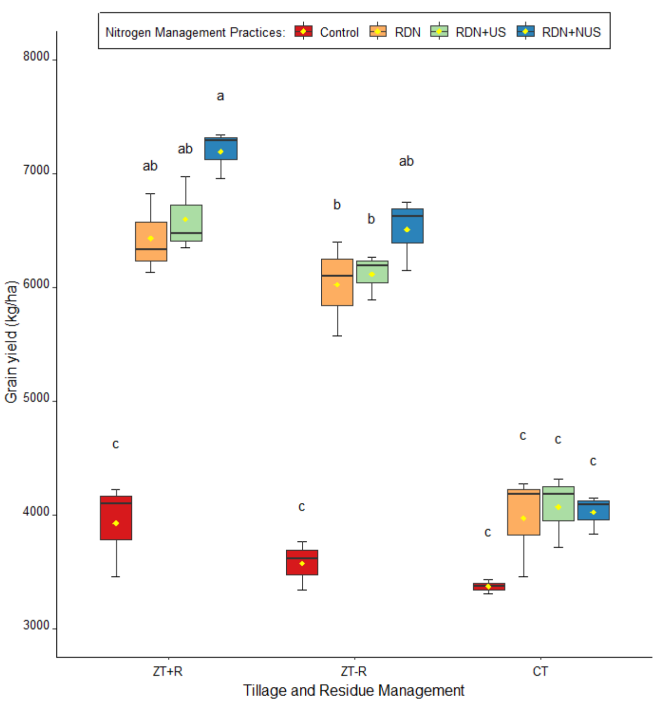

Figure 3. Effect of tillage and nitrogen management practices on yield of maize

improved exploitation of nutrient depots (Zhang *et al*., 2000; Arkoun *et al*., 2012). The deep N placement helps to delay the senescence of the aboveground parts of maize and maintain high biomass during the later growth period, which results in yield benefits (Hocking *et al*., 2003; Su *et al*., 2015; Liu *et al*., 2015).

Conclusion

The ZT+R resulted in higher growth parameters of maize at all stages due to better nutrient availability, moisture retention, and improved soil structure. Nitrogen management practices also had a substantial impact, with the highest plant height and DMA observed under NMP1 (100% RDN) initially. However, the NPM3 i.e. 75% RDN with better placement and two 3% urea sprays improved growth at later stages, indicating that strategic nitrogen placement further optimizes growth. Root parameters, including root density and weigh were significantly higher under ZT+R due to improved soil conditions. Overall, the combination of ZT+R and optimized nitrogen management practices fosters a more conducive environment for crop growth, leading to superior growth metrics in maize cultivation.

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