Vol. 23, No. 2, pp. 180-195 (2023)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Long-term Impact of Tillage, Residue, Nitrogen and Irrigation Management on Growth, Yield and Nitrogen Productivity of Maize under Maize-Wheat Rotation in North-Western India

SUJAN ADAK[1], K.K. BANDYOPADHYAY[4,*], R.N. SAHOO[1], P. KRISHNAN[1], V.K. SEHGAL[1], S.N. KUMAR[2], S.P. DATTA[3], A. SARANGI[4], R.S. BANA[5], NANDITA MANDAL[1], PRIYA BHATTACHARYA[1], AND MD YEASIN[6]

[1]*Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi-110012*
[2]*Division of Environment Sciences, ICAR-Indian Agricultural Research Institute, New Delhi-110012*
[3]*Indian Institute of Soil Science, ICAR-Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh*
[4]*ICAR-Indian Institute of Water Management, Bhubaneswar-751023, Odisha*
[5]*Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi-110012*
[6]*Division of Agricultural Statistics, ICAR-Indian Agricultural Statistics Research Institute, New Delhi-110012*

ABSTRACT

In north-western India, maize-based systems are being advocated as an alternative to rice-based systems to address the issues of resource degradation, particularly declining soil health, water tables and climate change-induced variability in rainfall and temperature. Conservation agriculture (CA) based best-bet crop management practices may increase crop and nitrogen (N) productivity, while conserving and sustaining natural resources. In a six-year-old long-term experiment, we have evaluated the performance of varied tillage (conventional tillage (CT) and no tillage (NT)), crop residue (with residue mulch (R+) and without residue (R0), irrigation (full irrigation (IF) and deficit irrigation (ID)), and nitrogen management [50 (N50%), 100 (N100%) and 150 (N150%) percent of recommended dose of nitrogen (RDN) for maize)] in a split factorial design on crop yield and nitrogen productivity. NT plots had significantly higher pooled average (5.1 and 6.4%) grain yield, (3.7 and 3.7%) biomass productivity than the CT plots in 2019 and 2020, respectively. Maize productivity were significantly superior under residue mulching compared to no mulch (5.5% in 2019 and 4.2% in 2020) coupled with N application. Significantly higher pooled crop productivity (3.6% in 2019 and 11.8% in 2020) was observed in full irrigation than that of deficit irrigation. Nitrogen productivity of maize under NT with residue mulch was improved as compared to CT and no mulch plots, respectively. Partial factor productivity of nitrogen (PFPN) of maize showed negative relationship with increase in N rates. However, the PFPN improved with increase in irrigation levels. We conclude that maize may be grown under no tillage with crop residue mulch with full irrigation and 150% RDN to obtain higher crop productivity and with 50% RDN to obtain higher nitrogen productivity but there is yield penalty under 50% RDN treatment in north-western region of India. Therefore, maize should be grown under NT with crop residue mulch (CRM), 100% RDN and with full irrigation to obtain optimum grain yield and improve PFPN as against the conventional method in north-western region of India.

Key words: Conservation agriculture, Leaf area index, Maize productivity, Nitrogen productivity of maize

*Corresponding author,
Email: kk.bandyopadhyay@gmail.com

Introduction

Future food security in India faces significant issues as a result of the intense cereal-based systems and heavy conventional tillage in north-western India. Despite the fact that the country's food security is provided by the region's rice-wheat (RW) cropping sequence, but the over exploitation has led to falling water table (Hobbs and Gupta, 2000; Sharma *et al.*, 2012), leading to yield plateau. North-western India's rice-wheat system is mainly distinguished by heavy tillage and energy consumption (Jat *et al.*, 2013), high fertiliser use (Saha *et al.*, 2009), and high levels of irrigation (Das *et al.*, 2016). However, the sustainability of the RW system as a workable solution for long-term food and energy security has come under scrutiny due to diminishing biomass factor productivity and decreased resource and energy-use efficiency (Saharawat *et al.*, 2010). Therefore, it is being investigated whether an alternate crop rotation could aid this region under future harsh climatic conditions (Congreves *et al.*, 2015) by increasing biomass productivity, water and energy usage efficiency, and farm profitability (Das *et al.*, 2014). The diversification of rice with maize is another alternative efficient crop and cropping systems which are of more eco-friendly (Aulakh and Grant, 2008) for which the government is also advocating time and again. Under the recent climate change induced variability-maize is on advantageous side due to lower water requirement, it will be a better alternative to *kharif* (rainy) season rice of this region to enhance the crop as well as system productivity, and sustain soil health and environmental quality (Meelu *et al.*, 1979).

In the past, attempts were made to grow maize in a RW system as a substitute crop for rice using traditional management techniques, but they failed since rice was more profitable. However, high yielding maize hybrids have recently made genotypic choices for crop diversification available with the introduction of single cross hybrid (SCH) technology and the development of varied maturities (extra early, early, medium, and late). An essential crop for India's food and nutritional security, maize is farmed there on an 8.67 million ha area in a variety of seasons and ecologies (GoI, 2015). More than 4.5 billion people in 94 developing nations depend on maize to deliver around 30% of their food's calories, and by 2050, that number is predicted to have doubled (Srinivasan *et al.*, 2004). To meet this demand, maize output must increase. In past one decade (2003-04 to 2012-13), maize area expanded by 1.8%, production increase by 4.9% and productivity growth at 2.6% per annum witnessed in India which was mainly because of increased maize demand (GoI, 2015). However, these hybrids alone not catching much attention of the growers under traditional crop management practices in North-Western India. The conservation agriculture (CA) based crop production technologies are attracting the attention of the growers in this region in the current situation to explore the maximum yield potential of hybrid maize under the emergence of overexploitation of natural resources, primarily soil and water as well as to offset the production costs and environmental impacts (Ladha *et al.*, 2009; Jat *et al.*, 2009; Saharawat *et al.*, 2012). The CA based crop management practices found to be effective for increasing growth and yield attributes of the crops (Jat *et al.*, 2014), crop productivity (Das *et al.*, 2014; Jat *et al.*, 2013), water-use efficiency (Jat *et al.*, 2014: Parihar *et al.*, 2016a). Additionally, the heavy traditional tillage operations result in a decrease in soil organic matter (SOM) due to increased oxidation and degradation of organic carbon, which in turn degrades soil characteristics (Biamah *et al.*, 2000; Gathala *et al.*, 2011). Globally, published experimental data have demonstrated improved productivity and soil quality, primarily as a result of SOM build-up (Ladha *et al.*, 2009; Bhattacharyya *et al.*, 2013) and higher SOC content under zero-tilled compared to conventionally tilled soils (West and Post, 2002; Alvarez, 2005, Parihar *et al.*, 2016b).

In the majority of agricultural systems, the physiological processes involved in plant growth are being compromised by poor nutrient and water availability, these variables are the principal causes of crop output limitations (Gonzalez-Dugo *et al.*, 2010). According to Teixeira *et al.* (2014) and Wang *et al.* (2017), nitrogen (N) is the most important nutrient needed by the maize crop since it is closely associated to the decrease in plant production and yield components. Due to the strong demand for inorganic N-based fertilizers, high application rates are frequently used throughout production, necessitating a reasonable management strategy that takes into account the practices' effects on the economy and environment (Djaman *et al.*, 2013; Jia *et al.*, 2014). The management of water resources is also linked to the success of agricultural output. In order to maximise resource efficiency and minimise the influence on yield, the amount of water available for irrigation has to be limited (Paolo & Rinaldi, 2008; Kresoviæ *et al.*, 2016). Given the foregoing, increased water and nitrogen usage efficiency is a desirable trait and is essential to raising and optimising agricultural productivity (Quemada & Gabriel, 2016).

Adoption of CA principles with 'Best–Bet' crop management practices would be helpful in expansion of maize area in North-Western India. So, to generate the new information for sustainable intensification of maize-based systems in North-Western India and systematic evaluation of its N productivity, a long-term study was initiated at ICAR-IARI research farm, New Delhi to evaluate the impacts of different tillage, residue, nitrogen, and irrigation management on the performance of intensified maize based cropping systems. In this paper, we are reporting the results on crop performance, yield, and partial factor of nitrogen productivity in kharif maize crop planted at fixed plots under different management practices.

Materials and Methods

Study area

The field experiments were conducted in the MB-4C research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India (28°35' N latitude, 77°12' E longitude, and at an altitude of 228.16 m above mean sea level) with *kharif* maize as a test crop under maize-wheat cropping system in a long-term field experiment (since 2014 continuing) during the years of 2019 and 2020.

Climate of experimental site

New Delhi is coming under sub-tropical semi-arid climate with a mean annual rainfall of 651 mm. The average amount of precipitation each year is 691 mm, of which 75% is brought in by the south-west monsoon from July to September. The average monthly minimum and maximum temperature in January (the coldest month) ranged between 5.9 and 19.9°C. The corresponding temperature in May (the hottest month) ranged between 24.4 and 38.6°C. The weather condition during crop growth period of the years 2019 and 2020 is depicted in Fig. 1.

Soil of experimental site

The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (>2 m), flat and well drained. The soil was mildly alkaline (pH 7.8), non-saline, low in organic C (Walkley and Black C) (4.1 g/kg) and available N (0.032%) and medium in available P (7.1 kg/ha) and K (281 kg/ha) content. The bulk density varied from 1.58 g/cm^3 in the 0-15cm layer to 1.72 g/cm^3 in the 90-120 cm layer. Available soil moisture content ranged from 24.6-28.3% (0.033 MPa) to 9.7-12.9 % (1.50 MPa) in different layers of 0-120 cm soil depth.

Experimental details

The experiment was laid out in a split factorial design with three replications. The main plot factors comprise of two levels of tillage (Conventional tillage (CT), and No-tillage (NT)) and two levels of crop residue mulching (with residue mulch (R+) @ 5t/ha and residue removal (R0)). The sub-plot factors comprise of three levels of nitrogen dose (75 (N50%), 150 (N100%), and 225 (N150%) kg/ha i.e., 50, 100 and 150% of the recommended dose of nitrogen) and two levels of irrigation (full irrigation (IF) and deficit irrigation (ID)).

Crop management

Maize crop (cv. PMH1) was sown on the 6^{th} and 21^{st} of July in 2019 and 2020, respectively with a row spacing of 60 cm at a seed rate of 25 kg ha^{-1}. The crop was harvested in the third week of October. A fertilizer dose of 150 kg N + 75 kg P_2O_5 + 75 kg K_2O was followed as a recommended dose (N100% treatment). An N fertilizer dose of 75 and 225 kg of N/ha was applied for N50% and N150% treatment, respectively while other fertilizer doses remained the same. 20% of N and the entire dose of P, and K were applied as the basal at the sowing time. The remaining N was applied in three splits of 20% at the four-leaf stage, 30% at knee high stage and 30% at flowering stage. Under the full irrigation (IF) treatments,

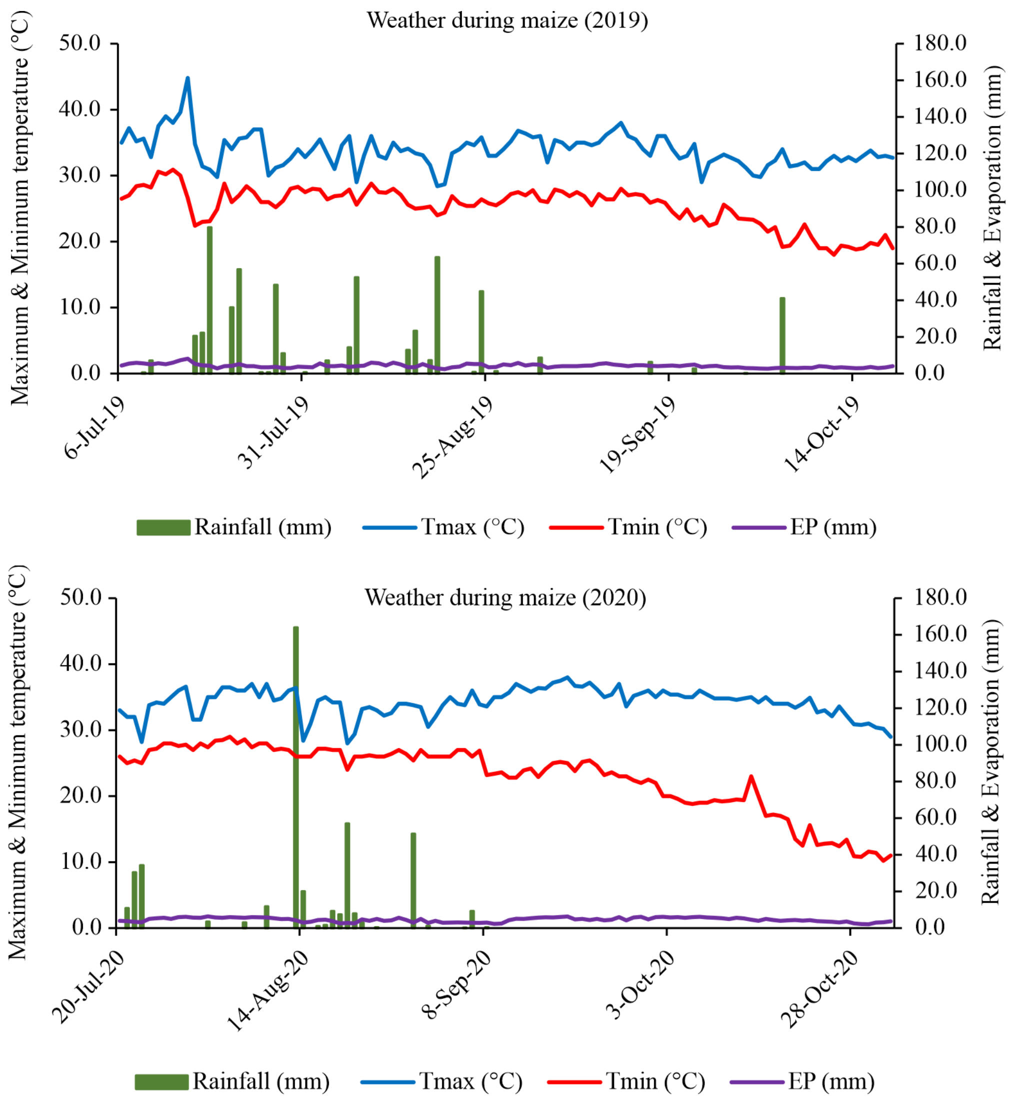

Fig. 1. Daily weather condition during maize growth period of the years 2019 and 2020

irrigation was applied at critical stages (four leaf, knee high, tasseling, silking and soft dough) @ 6 cm and in dry spells or periods without rainfall. Under the deficit irrigation (ID) treatments, irrigation was applied only to four leaf, knee high, and silking. Conventional tillage (CT) was implemented with one ploughing with the help of a disc harrow followed by a spring-tine cultivator in CT treatment whereas the crop was directly drilled using a ZT multi-crop planter in NT treatments. In the residue mulch treatment, the previous season's wheat residue was applied as a mulch @ 5 t/ha after 10 DAS of the maize crop. In the NT plots, weeds were managed by the application herbicide. The field was kept weed free by employing pre-emergence herbicide and 3-4 times manual weeding during crop growth stages under CT plots.

Leaf area index (LAI)

Measurements of Leaf Area Index were carried out in the field at 15 days intervals using LAI- 2000 Plant Canopy Analyzer (LI-COR, USA), whose principle is based on "fish-eye" measurement of diffuse radiation interception by measurement of gap fraction at five zenith angles (0–13, 16-28, 32–43, 47–58, 61–74°) simultaneously. The measured gap fractions are then inverted to get the effective LAI and the instrument was set to take three below and one above canopy measurements to estimate the LAI. LAI readings were taken from each replication of each treatment.

Grain and biomass yield

The maize crop was harvested at physiological maturity, in the third week of October in both the years. The data of grain and biomass yields were estimated from harvested net plots (after excluding the border rows from both directions). The grain and above ground biomass (AGB) yield were calculated and represented as kg/ha at 12% moisture content.

Partial factor productivity of nitrogen

The partial factor productivity of nitrogen was calculated using the following formula,

PFPN=GY/FN

where, PFPN= Partial factor productivity of nitrogen (kg grain/kg N applied), GY= *Kharif* corn yield (kg/ha), FN= Nitrogen application amount (kg/ha)

Statistical analysis

Data on crop productivity were subjected to analysis of variance (ANOVA) as applicable to split factorial design according to the method described by Bingham *et al.* (2004), and means between treatments were compared by least significant difference using Duncan's Multiple Range Test (DMRT) at 5% probability level.

Results and discussion

Leaf area index (LAI) of maize

The leaves of a plant are normally its main organ of photosynthesis and the total area of leaves per unit ground area, called leaf area index (LAI), and it is an important biophysical descriptor of crop canopies. The temporal profile of the growth of maize LAI under different tillage, residue, nitrogen, and irrigation management treatments in 2019 and 2020 are shown in Fig. 2. A smooth pattern of LAI growth during the growing season was exhibited by fitting data using 2nd order polynomial. It shows the typical growth pattern, the initial phase showed an increase in leaf area, then reached a peak at silking stage followed by a decline due to senescence. The maximum LAI (LAI_{max}) was attained at 60 and 55 DAS in the year of 2019 and 2020, respectively. LAI of the maize confirmed the variable growing environment under CT and NT practices. In 2019, the LAI_{max} was 4.6% higher ($p<0.05$) in NT compared to CT while the increment was 3.4% in 2020 (Fig. 2a, 2b). Similarly, LAI_{max} under CRM treatments was 6.3 and 7.6% higher than that of no mulch treatments in 2019 and 2020, respectively (Fig. 2c, 2d). Significantly higher LAI under no-tillage and residue retention could be attributed to more favourable growth conditions in CA. Better aggregation, more soil water retention, and lower penetration resulted in better canopy development in maize under CA than CT (Kutu, 2012). Averaged over tillage, residue, and irrigation management, LAI_{max} in N150% treatment was higher than N100% and N50% treatments by 11.4 and 45.7%, respectively in 2019 and by 5.5 and 31.8%, respectively in 2020, while N100% treatment enhanced LAI_{max} than that of N50% treatment by 30.5 and 24.92% in the year of 2019 and 2020, respectively (Fig. 2e, 2f). Higher LAI with increased N application could be attributed to significant increases in leaf expansion (length and breadth) resulting from cell division and cell enlargement at higher N rates. Similar results were reported by Pradhan *et al.* (2018) for wheat; Wright (1982) and Kar and Kumar (2015) for maize, and Shafi *et al.* (2011) for barley. Similarly, averaged over tillage, residue, and N management, IF plots attained 11.3% higher LAI_{max} compared to ID plots in 2020 (Fig. 2h) whereas it was comparable in the year 2019 (Fig. 2g).

Grain and biomass yield of Maize

The grain and biomass yield of maize as affected by tillage, residue nitrogen and irrigation management are presented in Fig. 3 and 4, respectively. The interaction effect of tillage, residue, nitrogen, and irrigation management interaction on maize grain and biomass yield is presented in Table 1. The grain and above ground biomass (AGB) yield under NT was higher than that of CT by 5.1 and 3.7%, respectively in 2019 (Fig 3a, 4a) and by 6.4 and 3.7%, respectively in 2020 (Fig 3b, 4b). Crop residue mulch improved the grain yield than that of no mulch treatment by 5.5 and 4.2% in 2019 and 2020, respectively (Fig 3c, 3d). Similarly, there was 1.06- fold improvement

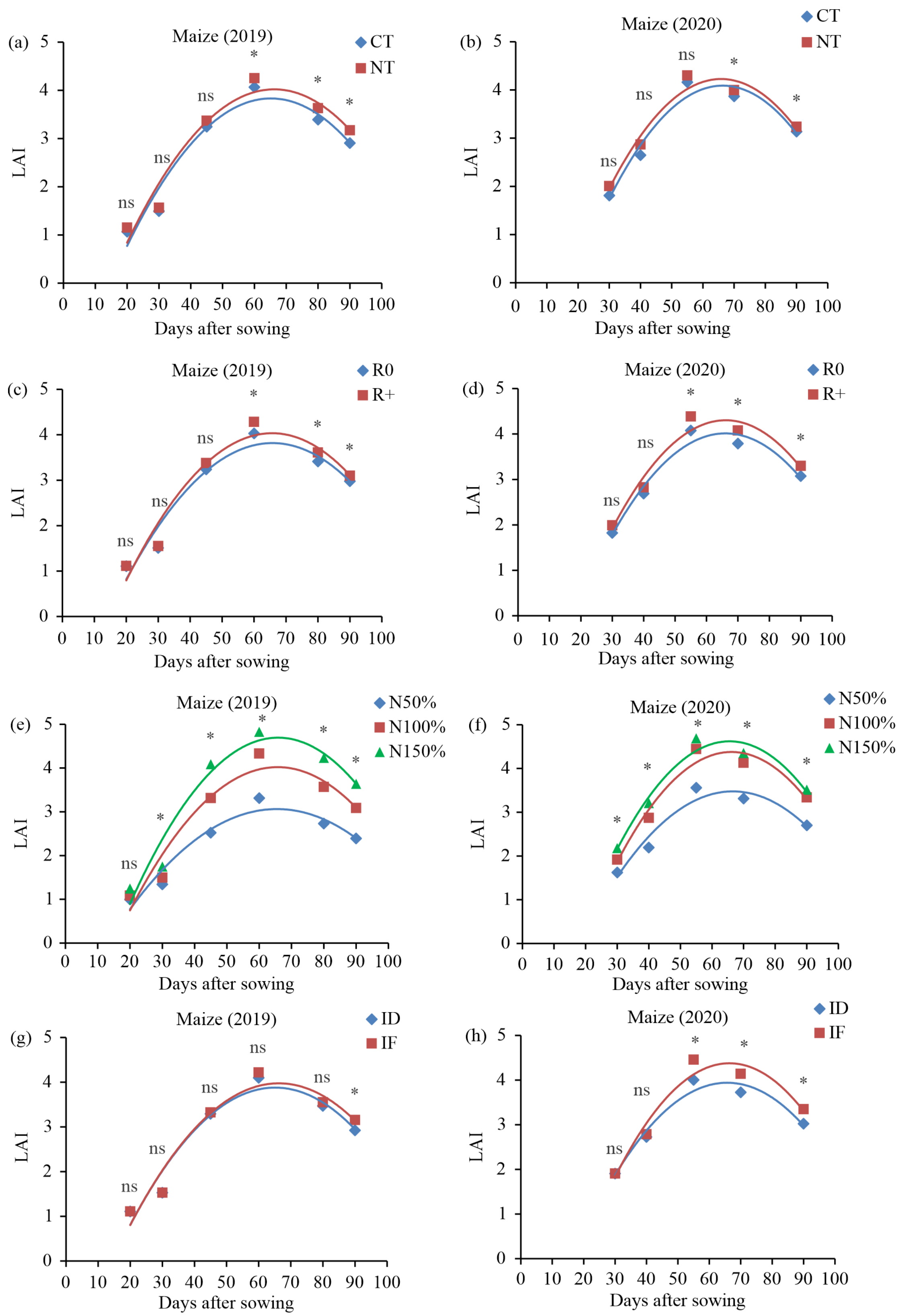

Fig. 2. Leaf area index (LAI) of maize as influenced by tillage, residue, nitrogen, and irrigation management in the season 2019 and 2020

Table 1. Grain and biomass yield of maize as influenced by Tillage × Residue × Nitrogen × Irrigation management interaction in the season 2019 and 2020

Treatments	Grain yield (kg/ha)		Biomass yield (kg/ha)	
	2019	2020	2019	2020
CTR0N50%ID	3473[l]	3350[l]	10586[j]	10533[l]
CTR0N50%IF	3638[l]	3509[kl]	11401[i]	11684[jk]
CTR0N100%ID	5130[i]	4354[h]	15303[f]	12620[hi]
CTR0N100%IF	5286[ghi]	5035[fg]	15375[f]	15872[de]
CTR0N150%ID	5457[efg]	4960[g]	16385[bcd]	14480[fg]
CTR0N150%IF	5629[cde]	5610[cd]	16218[cde]	17451[bc]
CTR+N50%ID	3519[l]	3540[jkl]	10710[j]	11124[kl]
CTR+N50%IF	3891[k]	3795[ij]	12317[h]	12731[hi]
CTR+N100%ID	5245[hi]	4478[h]	15648[ef]	13128[h]
CTR+N100%IF	5338[fgh]	5259[ef]	15698[ef]	16741[cd]
CTR+N150%ID	5487[ef]	5036[fg]	16892[ab]	15279[ef]
CTR+N150%IF	5676[bcd]	5869[bc]	16962[ab]	18970[a]
NTR0N50%ID	3481[l]	3539[jkl]	10582[j]	11095[kl]
NTR0N50%IF	3539[l]	3718[ijk]	10832[ij]	12066[ij]
NTR0N100%ID	5235[hi]	4571[h]	15340[f]	13018[h]
NTR0N100%IF	5469[efg]	5332[e]	15866[def]	16726[cd]
NTR0N150%ID	5576[de]	5345[de]	16476[bcd]	15350[ef]
NTR0N150%IF	5732[bcd]	6046[ab]	16853[abc]	18198[ab]
NTR+N50%ID	4090[i]	3812[i]	12692[gh]	12197[hij]
NTR+N50%IF	4202[j]	3871[i]	13265[g]	12947[hi]
NTR+N100%ID	5680[bcd]	4909[g]	16780[bc]	14253[g]
NTR+N100%IF	5824[b]	5474[de]	16859[abc]	17123[c]
NTR+N150%ID	5813[bc]	5488[de]	16985[ab]	15747[e]
NTR+N150%IF	6048[a]	6172[a]	17442[a]	18193[ab]
LSD (T×R×N×I)	187	658	859	933

#Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT

in the AGB under R+ as compared to R0 in both the years (Fig 4c, 4d). The higher system yield under CA based PB and ZT practices were also reported by Parihar *et al.* (2016a). Improved soil water supply, rooting depth and crop yields through the use of minimum tillage techniques have been also reported in the semi-arid regions of Kenya (Gicheru *et al.*, 2004; Rockström *et al.*, 2009). In contrast to our findings, Lahmar (2010) summarized that crop yields were lower in CA compared with CT practices on fertile soils of Europe. The present findings of higher maize yield under NT and residue retention could be due to the compound effects of additional nutrients (Blanco-Canqui and Lal, 2009; Kaschuk *et al.*, 2010), improved soil physical health (Jat *et al.*, 2013; Singh *et al.*, 2016), better water regimes (Govaerts *et al.*, 2009) and improved nutrient use efficiency compared to CT (Unger and Jones, 1998). N150% treatment registered 52.2 and 52.8% higher grain yield compared to N50% treatment during the years 2019 and 2020, respectively. Whereas, N150% treatment registered 5.1 and 13.0% higher grain yield compared to N100% treatment during the years 2019 and 2020, respectively. Similarly, N100% treatment registered 44.8 and 35.3% higher grain yield compared to N50% treatment during the years 2019 and 2020, respectively (Fig 3e, 3f). Ma *et al.* (2006) and Qian *et al.* (2016) studied different hybrid varieties of maize and found that nitrogen fertilization significantly increased the grain yield per plant and

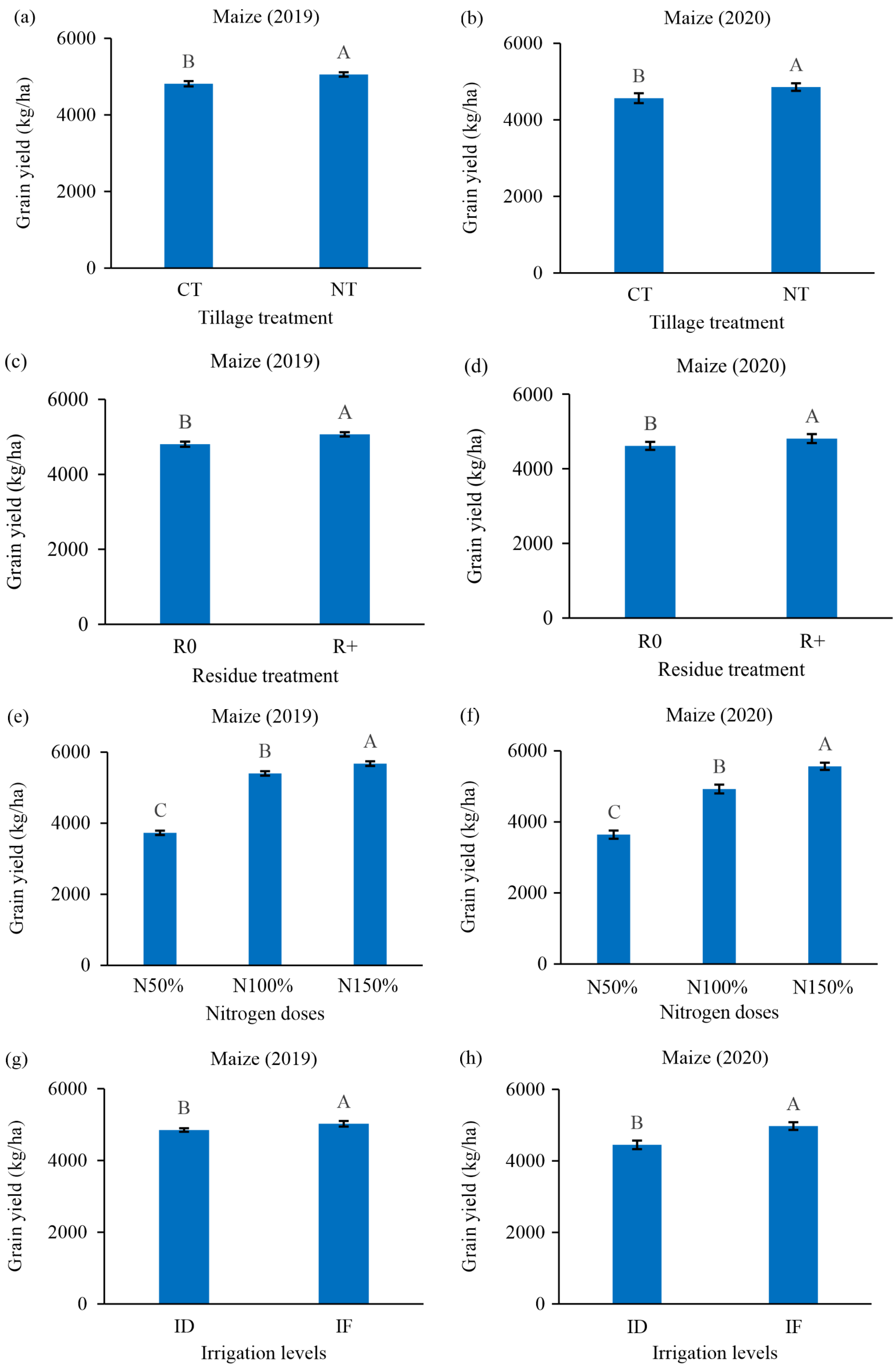

Fig. 3. Maize grain yield as influenced by tillage, residue, nitrogen, and irrigation management in the season 2019 and 2020

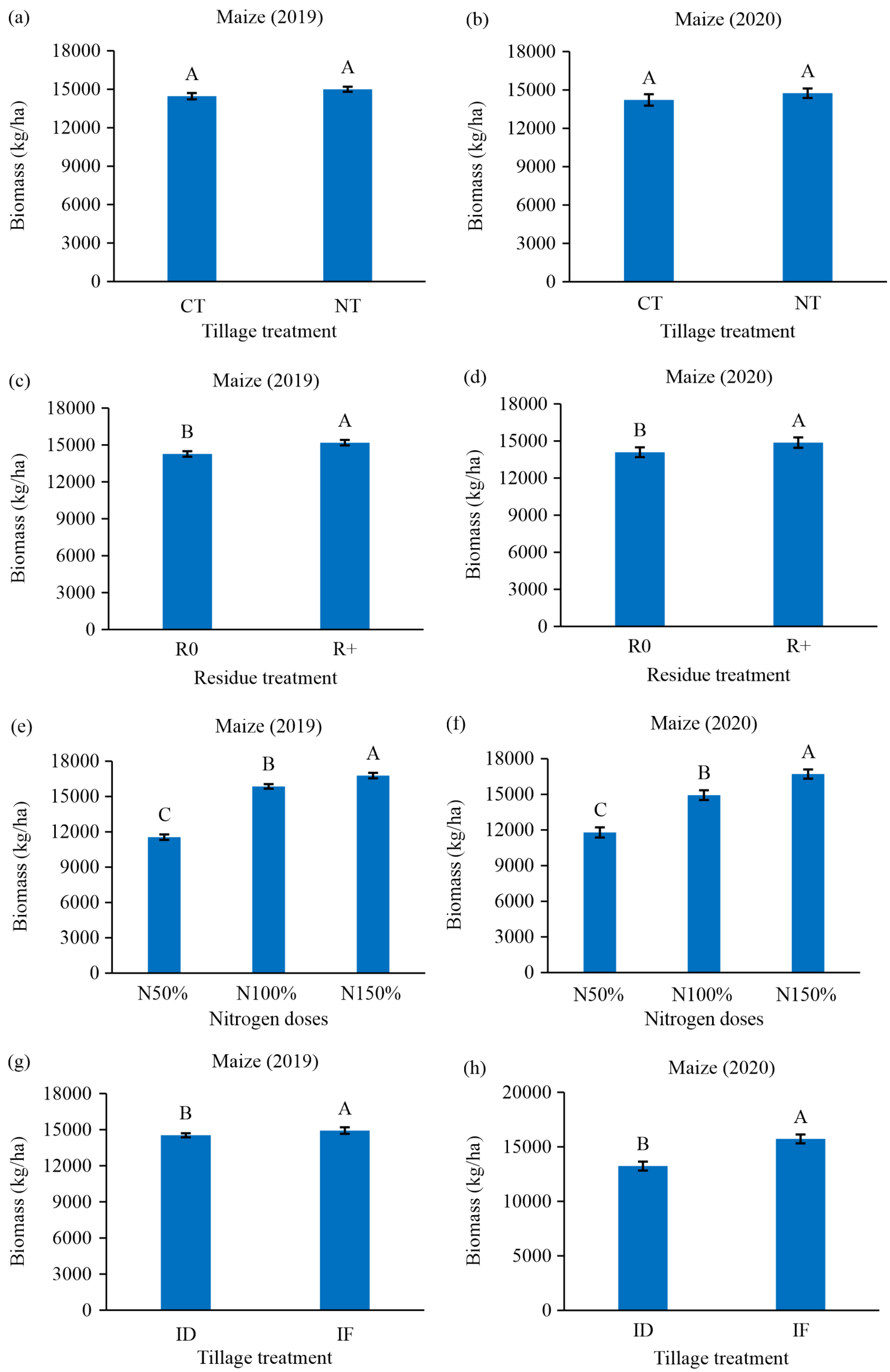

Fig. 4. Biomass yield of maize as influenced by tillage, residue, nitrogen, and irrigation management in the season 2019 and 2020

per unit area. Similarly, the AGB increased with the increase in N applications, which is supported by results from other studies also (Azeez *et al.*, 2006; Barbieri *et al.*, 2008; Jin *et al.*, 2012; Chen *et al.*, 2015; Hammad *et al.*, 2017). These results can be attributed to increased LAI, green spikes area, and crop duration with greenness, which resulted in the increased interception of radiation (Adak *et al.*, 2021; Latiri-Souki *et al.* 1998). In both the years of study, grain yield increased significantly with the increased level of irrigation. The grain and above ground biomass (AGB) yield under full irrigation (IF) was higher than that of deficit irrigation (ID) by 3.6 and 2.7%, respectively in 2019 and by 11.8 and 18.8%, respectively in 2020. The higher yield with increasing levels of irrigation is attributed to better water and nutrient availability, which gave rise to better plant growth and yield. Similar results have been reported in maize by Campelo *et al.*, (2019). The interaction effect of tillage, residue, N, and irrigation management was significant on the grain yield and AGB of both the years of study. The highest grain yield was observed in NTR+N150%IF (6048 kg/ha in 2019 and 6172 kg/ha in 2020) and lowest in CTR0N50%ID (3473 kg/ha in 2019 and 3350 kg/ha in 2020) treatment for both the year of study. Similarly, the highest AGB yield were observed in NTR+N150%IF (16584 kg ha^{-1} in 2019-20 and 18193 kg/ha in 2020) and lowest in NTR0N50%ID (10582 kg/ha) in 2019 and CTR0N50%ID (10533 kg/ha) in 2020.

Partial factor productivity of nitrogen (PFPN) of maize

The effect of tillage, residue, nitrogen, and irrigation management and their interaction on the water productivity is presented in Fig. 5 and Table 2, respectively. During the year 2019, highest and lowest PFPN was found in NTR+N50%IF (56.03 kg grain/kg N applied) and CTR0N150%ID (24.26 kg grain/kg N applied) treatments, respectively while the corresponding values in the year 2020 were registered in the treatments NTR+N50%IF (51.61 kg grain/kg N applied) and CTR0N150%ID (22.05 kg grain/kg N applied), respectively (Table 2). In 2019, NT improved the PFPN by 6% as compared to CT in 2020 whereas it was statistically at par in 2020 (Fig 5a, 5b). PFPN under residue mulch treatment was 7.0 and 4.9% higher than that of no mulch treatment in 2019 and 2020, respectively (Fig. 5c, 5d). PFPN is positively related to yield performance of the crops. Similarly, NT with residue mulching recorded the higher PFPN was also due to significantly higher grain yield of maize. It also indicated that recycling of wheat residue in maize has contributed in enhancing the PFPN of maize. Sharma *et al.* (2010) also reported that mulching is useful practice in rainfed areas for controlling erosion, weed growth and conserving moisture as well as nutrients in the soil profile. However, PFPN of maize decreases with increase in nitrogen doses. Averaged over tillage, residue, and irrigation management, PFPN in N50% treatment was higher than N150% and N100% treatments by 97.1 and 27.6%, respectively in 2019 and by 96.3 and 32.4%, respectively in 2020 (Fig 5e, 5f). Whereas application of 150 kg N ha^{-1} enhanced PFPN than that of 225 kg N ha^{-1} by 42.7 and 32.8% in the year of 2019 and 2020, respectively (Fig 5e, 5f). Decline in partial factor productivity of nitrogen at higher level of N may be attributed to nutrient imbalance and decline in indigenous soil N supply. Several other studies reported were also found in good agreement with the results of our study (Moll *et al.*, 1982; Montemurro *et al.*, 2006; Gheysari *et al.*, 2009; Chen *et al.*, 2015; Kiani *et al.*, 2016; Amanullah, 2016; Qiu *et al.*, 2015; Adak *et al.*, 2019). Karim and Ramasamy (2000) suggested that higher fertilizer use efficiency which is always associated with low fertilizer rate, cultural practices meant for promoting integrated nutrient management will help to effect saving in the amount of fertilizer applied to the crops and there to improve fertilizer use efficiency. Stamatiadis *et al.* (2016) also reported that there is a negative relationship between fertilizer rate and NUE, as the nitrogen losses are rapid when the nitrogen inputs surpass the crop assimilation capacity (Meisinger *et al.*, 2008; Zhu *et al.*, 2016; Jin *et al.*, 2012). PFPN of maize under full irrigation increased as compared to deficit irrigation by 3.9 and 9.9% in 2019 and 2020, respectively (Fig 5g, 5h). This could be explained by a number of things. The first relationship between water and biological processes is that of biological macromolecules and membranes, enzyme synthesis and activity, nitrate reductase activity, metabolism and physiology, and several

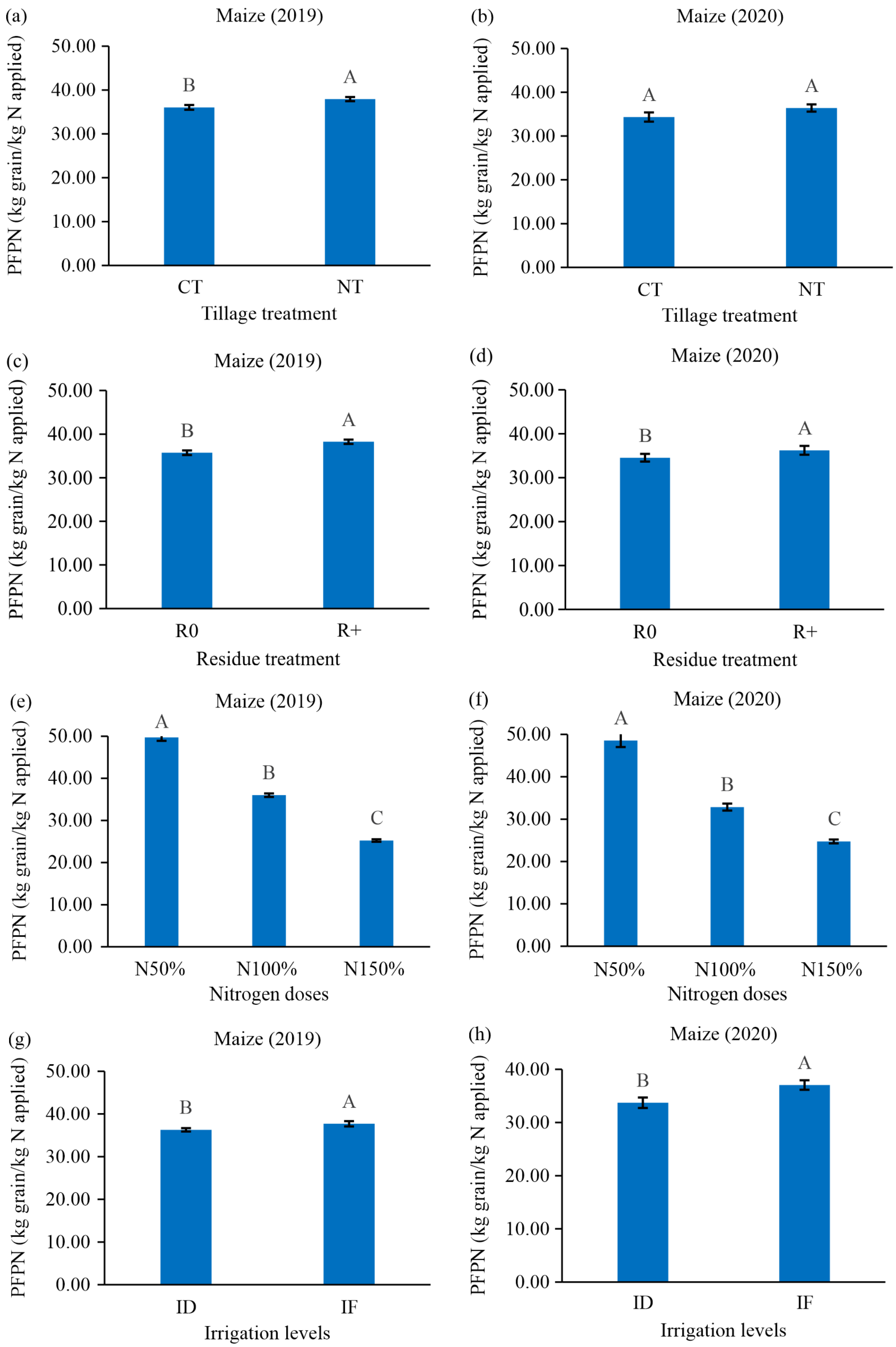

Fig. 5. Biomass yield of maize as influenced by tillage, residue, nitrogen, and irrigation management in the season 2019 and 2020

Table 2. Partial factor productivity of nitrogen in maize as influenced by Tillage × Residue × Nitrogen × Irrigation management interaction in the season 2019 and 2020

Treatments	Partial factor productivity of N (kg grain/kg N applied)	
	2019	2020
CTR0N50%ID	46.31[d]	44.66[d]
CTR0N50%IF	48.50[c]	46.78[c]
CTR0N100%ID	34.20[h]	29.02[hi]
CTR0N100%IF	35.24[gh]	33.57[fg]
CTR0N150%ID	24.26[j]	22.05[n]
CTR0N150%IF	25.02[ij]	24.93[klm]
CTR+N50%ID	46.92[cd]	47.20[c]
CTR+N50%IF	51.88[b]	50.60[ab]
CTR+N100%ID	34.97[gh]	29.85[h]
CTR+N100%IF	35.58[gh]	35.06[ef]
CTR+N150%ID	24.39[j]	22.38[n]
CTR+N150%IF	25.23[ij]	26.08[jkl]
NTR0N50%ID	46.41[d]	47.18[c]
NTR0N50%IF	47.18[cd]	49.57[b]
NTR0N100%ID	34.90[gh]	30.47[h]
NTR0N100%IF	36.46[gh]	35.54[ef]
NTR0N150%ID	24.78[j]	23.75[mn]
NTR0N150%IF	25.48[ij]	26.87[jk]
NTR+N50%ID	54.53[a]	50.83[ab]
NTR+N50%IF	56.03[a]	51.61[a]
NTR+N100%ID	37.87[ef]	32.73[g]
NTR+N100%IF	38.83[e]	36.49[e]
NTR+N150%ID	25.83[ij]	24.39[lm]
NTR+N150%IF	26.88[i]	27.43[ij]
LSD (T×R×N×I)	1.93	1.98

#Values in a column followed by same letters are not significantly different at pÂ0.05 as per DMRT

other processes in plant life (Hsiao, 1973). Second, N availability in the soil and its movement to the roots are influenced by the amount of soil moisture (Hu *et al.,* 2009), making water availability a key factor in N uptake. Due to the slowed mineralization process and decreased root activity, severe water stress has been demonstrated to affect crop N availability (Shao *et al.,* 2013).

Conclusion

Study results indicated that grain yield of maize increased significantly under NT and crop residue mulching. So, this practice may be recommended in the IGP region for saving of energy and improving soil health. Crop residue mulching significantly improved the partial factor productivity of nitrogen. The grain yield of maize increased with the increase in the N level whereas the PFPN decreased with higher nitrogen levels. Therefore, maize grown under NT with crop residue mulch (CRM), 150%RDN and with full irrigation has the potential to obtain higher grain yield but with 50% RDN to obtain higher PFPN. But there should be trade-off between grain yield and PFPN, so that we can improve the PFPN without any significant loss of yield. Thus, maize should be grown under NT with crop residue mulch (CRM), 100%RDN and with full irrigation to obtain optimum grain yield and improve PFPN as against the conventional tillage in north-western region of India.

Acknowledgement

The first author acknowledges the help received from Department of Science and Technology, Government of India in the form of DST-Inspire Fellowship during the study period. The logistic support received from the Director, IARI during the study period is thankfully acknowledged.

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Received: 10 September 2023; Accepted: 22 November 2023