



Effect of conservation agriculture on soil fertility in maize (*Zea mays*)-based systems

AMRESH CHAUDHARY¹, MAHESH C MEENA², B S DWIVEDI³, S P DATTA⁴, C M PARIHAR⁵,
ABIR DEY⁶ and V K SHARMA⁷

ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

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ABSTRACT

A long-term field experiment on conservation agriculture (CA) was initiated in sandy loam soil of Indo-Gangetic plain in 2008 at Research Farm of ICAR-IARI, New Delhi with 3 tillage practices, i.e. permanent bed (PB), zero-tillage (ZT) and conventional tillage (CT) in main plots and four maize-based cropping systems, i.e. maize-wheat-mungbean (MWMb), maize-chickpea-*sesbania* (MCS), maize-mustard-mungbean (MMuMb), maize-maize-*sesbania* (MMS) in sub-plots, in a split-plot design with three replications to evaluate the long-term effects of CA practices on maize yield and soil fertility under maize-based cropping systems. The current study was undertaken in *kharif* maize 2015 after completion of seven years of experimentation. Soil fertility parameters like mineral nitrogen (N) (NO_3^- and NH_4^+), available phosphorus (P), potassium (K), sulphur (S) and micronutrients (Zn, Fe, Mn, Cu) were determined from 0–5, 5–15 and 15–30 cm of soil depths. The available macronutrients (N, P, K and S) and micronutrients (Zn, Fe, Mn, Cu) were higher under PB and ZT compared with CT. Among the cropping systems, MCS and MWMb performed equally in relation to nutrient availability. The grain yield of maize was significantly higher under PB (5.55 t/ha) and ZT (5.49 t/ha) as compared to CT (4.81 t/ha), whereas MCS and MWMb performed better in term of maize productivity as compared with MMuMb and MMS. Thus, the long-term study suggested that ZT and PB under diversified cropping systems such as MWMb and MCS could be the best agricultural practices for sustainable production as well as nutrient availability in maize-based cropping systems.

Key words: Conservation agriculture, Maize-based cropping systems, Soil fertility

Conservation agriculture (CA) is becoming popular worldwide due to its enhanced C sequestration potential and favourable effects on soil fertility and nutrient dynamics (Wright *et al.* 2007, Dey *et al.* 2016, Kumawat *et al.* 2018, Choudhary *et al.* 2019). Conservation agriculture based on principles of zero tillage (ZT), residue retention and crop diversification improves physical, chemical and biological properties of the soil (Hobbs *et al.* 2008). However, CA-based practices may change the soil-profile distribution of nutrients compared to conventional tillage (CT) (Wright *et al.* 2007, Martinez *et al.* 2016). Nutrient distribution in soil under CT is more uniform due to mixing of soil along with crop residues, fertilizers and manure (Martinez *et al.* 2016).

Cropping systems also have a great influence on distribution of plant available nutrients in soil profile which may be affected by nutrient removal, decomposition of crop

residues retained on the soil surface and nutrient leaching (Wright *et al.* 2007). Diversification in cropping systems can change the quality and quantity of crop residues due to their different C:N ratios and decomposition pattern, which are retained on the soil surface (Dey *et al.* 2016, Choudhary *et al.* 2019). Thus, the interaction of tillage and cropping systems can ultimately result into nutrient stratification (Wright *et al.* 2007).

Indian soils are suffering from multi-nutrient deficiencies due to application of unbalanced fertilizer doses and lack of organic amendments in croplands (Meena *et al.* 2017, Amit-Kumar *et al.* 2018). Therefore, it is important to understand how these systems influence nutrient distribution under different tillage regimes and cropping systems and ultimately crop yields. The objective of the present study was to quantify the distribution of plant-available macro and micronutrients under maize-based cropping systems at 0–30 cm soil depth in sandy loamy soil of Typic Haplustept after 7 years of experimentation, which provides an important information for understanding the nutrient distribution in soil.

MATERIALS AND METHODS

The long-term on-going field experiment was initiated

¹Ph D Scholar (amu8805@gmail.com), ²Senior Scientist (mcmeena@gmail.com), ³Head (bsdwivedi@yahoo.com), ⁴Professor (profssac2017@gmail.com), ⁶Scientist (abirdey21@gmail.com), ⁷Principal Scientist (vksharma.iari@gmail.com) Division of Soil Science and Agriculture Chemistry; ⁵Scientist (pariharc@gmail.com), Division of Agronomy, ICAR-IARI.

in 2008 at ICAR-IARI Research Farm, New Delhi (28°4' N latitude, 77°12' E longitude and 228.6 m amsl). The climatic condition of Delhi are sub-tropical with severe hot and cold environment. The soil was sandy loam in texture consisting of 64% sand, 12.6% silt and 23.40% clay, and classified as Typic Haplustert. Initial soil pH was 7.8, KMnO_4 oxidizable N 158 kg/ha, 0.5 M NaHCO_3 -extractable P 11.6 kg/ha and neutral 1 N NH_4OAc -extractable K 248 kg/ha. Three tillage systems as main-plots were established, in which two were CA-based practices [permanent bed (PB) and zero tillage (ZT)] and a conventional till (CT), and four maize-based cropping systems [maize-wheat-mungbean (MWMb), maize-chickpea-*Sesbania* (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-*Sesbania* (MMS)] as sub-plots. The experiment was conducted in split-plot design. Soil samples were collected from 0–5, 5–15 and 15–30 cm depths of soil in the month of October, 2015 after harvesting of maize. Half of soil samples were kept in freezer to determine the mineral N ($\text{NH}_4^+ + \text{NO}_3^-$) by extracting through 2 M KCl (Rowell 1994), and remaining half soil samples were air dried and ground to pass through a 2 mm sieve. Soil pH was measured in soil water suspension (1:2 soil:water). Available phosphorus (P) (Olsen *et al.* 1954), available K (Hanway and Heidel 1952), available S (Williams and Steinbergs 1959), and DTPA-extractable micronutrient (Lindsay and Norvell 1978) were determined. The maize grain yield was recorded as per standard protocols. The moisture content of grains was 15% and recorded yield was expressed in t/ha. Data recorded were analyzed using SAS 9.1 software (SAS Institute, Cary, NC) and ANOVA was performed to determine the significant differences ($P < 0.05$) among the tillage practices and cropping systems.

RESULTS AND DISCUSSION

Soil pH and plant-available macronutrients: Soil pH

was similar across the treatments irrespective of soil depth (Table 1). Soil pH, however, increased with soil depth. Soil pH increased non-significantly with respect to depths. Comparatively lower soil pH were observed under CA practices as compared to CT practices.

Soil mineral N, i.e. ($\text{NH}_4^+ + \text{NO}_3^-$) content was measured, and the NO_3^- content was higher under PB and ZT and decreased gradually with soil depths. Highest NH_4^+ content was recorded at 5–15 cm soil depth followed by 0–5 cm and 15–30 cm depths across the tillage practices. The recycling of the higher amount of previous crops residue due to higher biomass yield in these treatments lead to addition of more nutrients in ZT and PB practices compared to CT. On the other hand, the stover/straw was incorporated in deep soil layers under CT and leads to rapid decomposition and might also lead to leaching of mineralized nutrients in much deeper soil layers which in turn reduces content of plant available nutrients in CT (Dey *et al.* 2016, Martinez *et al.* 2016).

Among cropping systems, NO_3^- content was highest under MCS (18.6 to 28.0 mg/kg) across the soil depths. Lowest NO_3^- was recorded under MMS system. Similarly, NH_4^+ content was also significantly higher under MCS compared to other cropping systems as content varied from 15.8 to 19.3 mg/kg. A general trend of NO_3^- and NH_4^+ contents under the cropping systems was in the order: MCS > MWMb > MMuMb > MMS (Table 1). Reduced tillage systems support slowdown of SOM mineralization/decomposition and thus increase soil-N reserves compared to CT (Wright *et al.* 2007, Martinez *et al.* 2016). On the other hand, disruption of aggregates under CT makes SOM more accessible to soil micro-organisms and exposed to sunlight, thereby increasing N-mineralization from active and physically protected pools (Dey *et al.* 2016). Further, the pace of N-immobilization might be relatively less under CA

Table 1 Changes in soil reaction and mineral N under different tillage options and cropping systems

Treatment	Soil pH			NO_3^- (mg/kg)			NH_4^+ (mg/kg)		
	0-5 cm	5-15 cm	15-30 cm	0-5 cm	5-15 cm	15-30 cm	0-5 cm	5-15 cm	15-30 cm
<i>Tillage practices</i>									
Permanent bed	7.44	7.75	7.91	28.3	21.5	17.3	15.9	17.3	13.3
Zero tillage	7.34	7.76	7.83	27.1	20.1	18.0	15.1	16.6	14.4
Conventional tillage	7.6	7.81	7.87	19.6	15.9	12.4	10.5	11.8	9.8
LSD ($P = 0.05$)	NS	NS	NS	3.5	1.7	2.3	0.8	1.1	0.7
<i>Cropping systems*</i>									
MWMb	7.46	7.77	7.88	26.1	20.2	17.9	14.8	16.9	14.2
MCS	7.46	7.78	7.87	28.0	21.5	18.6	17.2	19.3	15.8
MMuMb	7.46	7.74	7.88	24.7	19.6	14.6	13.4	14.1	11.0
MMS	7.47	7.77	7.84	21.3	15.4	12.5	9.9	10.6	8.2
LSD ($P = 0.05$)	NS	NS	NS	2.3	2.1	1.8	0.9	0.9	0.9
Interaction LSD ($P = 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS

*MWMb: Maize-Wheat-Mungbean; MCS: Maize-Chickpea-*Sesbania*; MMuMb: Maize-Mustard-Mungbean; MMS: Maize-Maize-*Sesbania*

Table 2 Long-term effect of different tillage and cropping systems on depth-wise distribution of available P, K and S in soil

Treatment	Available nutrients (mg/kg)											
	P				K				S			
	0-5 cm	5-15 cm	15-30 cm	Mean	0-5 cm	5-15 cm	15-30 cm	Mean	0-5 cm	5-15 cm	15-30 cm	Mean
<i>Tillage practices</i>												
Permanent bed	14.3	11.8	9.2	11.8	93.0	89.3	79.2	87.2	17.6	11.9	6.8	12.1
Zero tillage	13.4	11.5	9.4	11.4	87.1	81.9	71.4	80.1	15.4	12.1	6.9	11.5
Conventional tillage	10.1	8.6	7.4	8.7	83.9	78.5	74.3	78.9	9.3	8.8	6.6	8.2
LSD (P = 0.05)	0.7	1.1	0.7		3.1	3.5	5.4		2.4	1.0	NS	
<i>Cropping systems</i>												
MWMB	13.5	11.4	9.0	11.3	94.0	88.2	83.4	88.5	16.8	12.8	7.4	12.3
MCS	13.6	12.0	9.6	11.7	86.4	79.5	77.4	81.1	12.8	10.2	6.2	9.7
MMuMb	11.9	9.9	8.2	10.0	82.9	78.2	74.2	78.4	10.8	8.6	6.0	8.5
MMS	11.3	9.3	7.7	9.4	88.7	79.2	78.4	82.1	16.1	12.0	7.4	11.8
Mean	12.6	10.7	8.6		88.0	81.3	78.4		14.1	10.9	6.8	
LSD (P= 0.05)	0.8	0.6	0.5		3.5	3.5	5.2		1.0	1.0	0.7	
Interaction LSD (P = 0.05)	0.8	NS	0.5		NS	NS	NS		1.7	1.8	NS	

due to surface retention of residues compared with residue incorporation and consequent enhancement in microbial activity. Among the cropping systems, highest mineral N content was recorded under MCS, and it contributed to higher mineral-N as compared with other cropping systems studied.

Available P content was highest in surface soil (0-5 cm) which decreased with soil depths irrespective of treatments (Table 2). The reduced tillage practices like PB and ZT significantly increased available P in soil depths compared to CT. Both PB and ZT showed similar effect on available P in all the depths. There is a sharp decline in P content, i.e. 17.4% from 0-5 to 5-15 cm, and 20.5% from 5-15 to 15-30 cm soil layers of PB system. Similar trend of nutrient stratification was also observed for ZT systems. Among cropping systems, available P in all depths was in the order: MCS>MWMB>MMuMb>MMS (Table 2). Available P content was similar in MWMB and MCS which was significantly higher than MMuMb and MMS in the surface soil. At deeper soil layers (5-15 cm and 15-30 cm), however, the differences were inconsistent (Amit-Kumar *et al.* 2018, Haokip *et al.* 2019).

Available K content in PB was significantly higher than CT and statistically at par with ZT in all soil depths. The similar findings for enhancing K in soils due to CA practices reported widely by several workers while working in different agro-climatic conditions throughout the world (Wright *et al.* 2007, Martinez *et al.* 2016). The K content in the 0-5 cm depth in PB among all the cropping systems was 18.2 (MMuMb) to 14.2% (MCS) higher than 5-15 and 15-30 cm soil depth. Available K content in the soil under different cropping systems was in the order: MWMB>MMS>MCS>MMuMb. Moreover, the chelation of these nutrients with organic matter in non-disturbed soil

lead the improvement of soil nutrient status in different soil depths. The similar enhancement in available nutrients due to CA practices in soil were also reported by Dey *et al.* (2016) for N, Kumawat *et al.* (2018) for P and Raghavendra *et al.* (2017) for K.

Available S content in soil was significantly affected by tillage practices as well as cropping systems. Available S was significantly higher under PB (17.6 mg/kg) and ZT (15.4 mg/kg) compared with CT (9.3 mg/kg) in 0-5 cm soil depth. In 15-30 cm depth, available S did not vary with tillage options. Among cropping systems, content of available S in the soil followed the trend: MWMB>MMS>MCS>MMuMb (Table 2). Highest values of available S were registered under MWMB which varied from 14.6 to 16.8 mg/kg, 12.8 to 15.4 mg/kg and 7.4 to 11.8 mg/kg for 0-5, 5-15 and 15-30 cm soil depth, respectively. This may be ascribed to relatively higher S demand of crops like mustard and chickpea involved in these cropping systems resulting in greater S removal from the soil (Meena *et al.* 2017). There is a significant reduction in S content in soil with each depth for all cropping system in CA based practices, i.e. PB and ZT. This can be explained with the fact that SOM is positively correlated with S and mineralization of SOM is the source of S in the soil. So, as the SOM content decreases with soil depth, S is also reduced (Shukla *et al.* 2017).

Available micronutrients: Irrespective of tillage practices and cropping systems, DTPA-extractable micronutrients were comparatively higher in surface (0-5 cm) soil, which gradually decreased with depth (Fig 1). However, DTPA-extractable micronutrients were higher than the deficiency threshold values for DTPA-micronutrients (Shukla *et al.* 2017). The CA practices, viz. PB and ZT did not differ significantly in the DTPA-Fe contents but variation was observed in depth-wise distribution of Fe in case of PB and

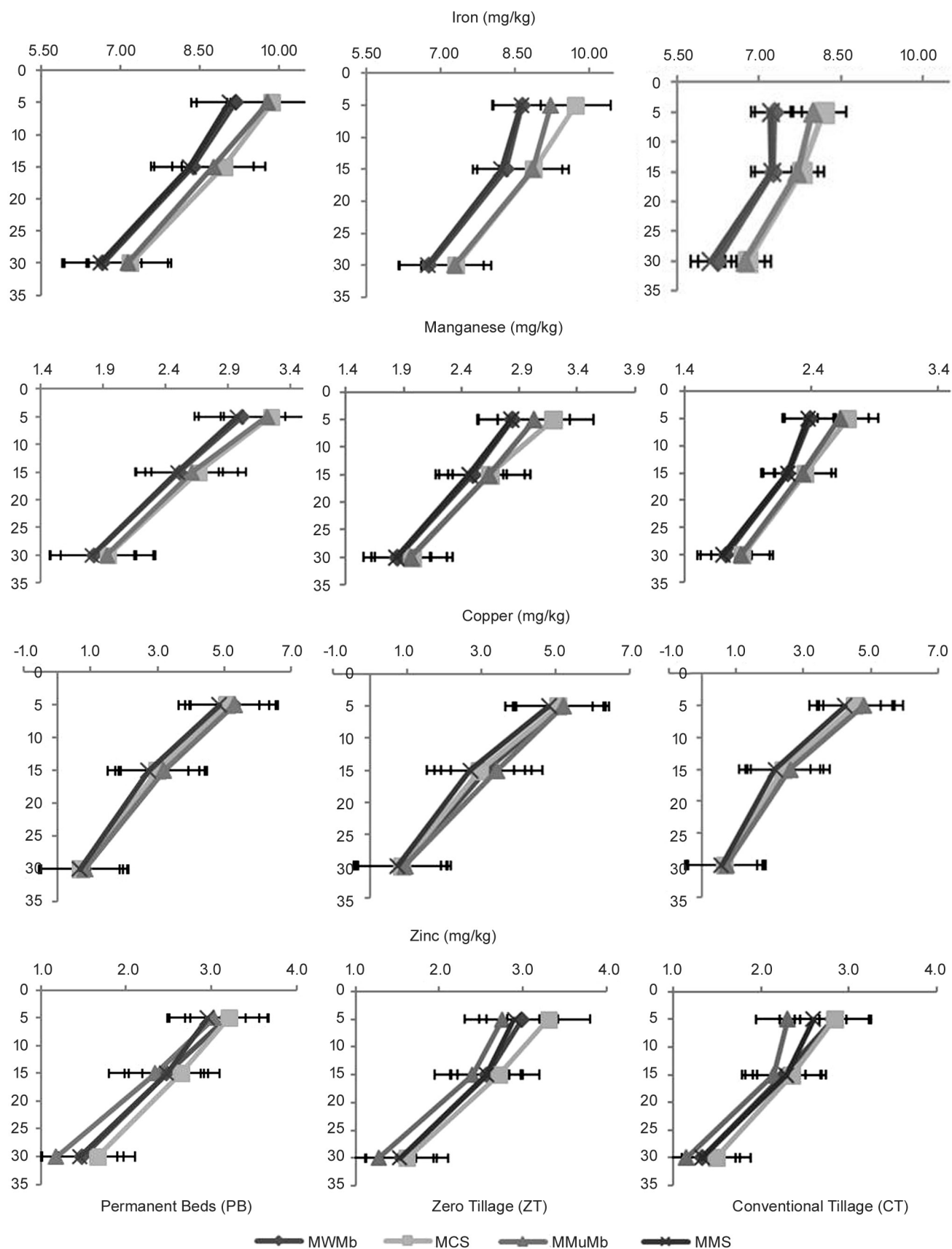


Fig 1 Depth distribution of plant-available Fe, Mn, Cu and Zn concentrations under long-term conservation agriculture based-PB and ZT and Conventional tillage practices under diversified intensive maize based cropping systems. Error bars represent the standard error of the mean.

Table 3 Correlations coefficient between maize yield and available plant nutrients (n = 36)

	Yield	NH ₄ ⁺	NO ₃ ⁻	P	K	S	Fe	Mn	Zn	Cu
NH ₄ ⁺	0.922***									
NO ₃ ⁻	0.845***	0.913***								
P	0.826***	0.880***	0.979***							
K	0.717**	0.603*	0.691*	0.646*						
S	0.666*	0.649*	0.823***	0.818***	0.687*					
Fe	NS	0.415	0.564	0.588*	0.512	0.730**				
Mn	0.650*	0.585*	0.700*	0.737**	0.539	0.819***	0.617*			
Zn	0.588*	0.392	0.565	0.589*	0.711**	0.706**	0.827***	0.767**		
Cu	NS	NS	NS	NS	0.651*	0.645*	0.661*	NS	0.675*	
pH	-0.518	-0.422	-0.603*	-0.590*	NS	-0.700*	-0.580*	-0.682*	-0.603*	NS

*, ** and *** indicate that the values of 'r' are significant at 5, 1 and 0.1% probability levels, respectively

ZT. Similarly, a decrease by 5.9 and 22% was observed in ZT system in 0-5 to 5-15 cm and 5-15 to 15-30 cm of soil depth, respectively. In case of CT, the trend of decrease in Fe content was only 4.2 and 14.9% in 0-5 to 5-15 cm and 5-15 to 15-30 cm of soil depth. The DTPA-Fe varied among the cropping systems as: MCS=MMuMb>MWmb=MMS. Data showed that MCS and MMuMb systems had similar DTPA-Fe contents, and the values were significantly higher than MMS and MWmb. Across the cropping seasons, highest DTPA-Fe content was recorded under MCS.

DTPA-Zn was also significantly higher under PB and ZT compared to CT. The increment was 23.7 and 23.6% under PB and ZT, respectively, across sampling depths. Among cropping systems, DTPA-Zn content followed the trend: MMuMb>MWmb>MCS>MMS (Fig 1). Similar to Fe and Zn, DTPA-Mn also followed the trend: PB>ZT>CT. The CA treatments had higher DTPA-Cu compared with CT. The PB and ZT, on an average had 13 and 12% higher DTPA-Cu over CT across soil depths. Among cropping systems, DTPA-Cu content was highest under MCS and lowest under MMuMb system across the seasons and soil depths. Depth-wise distribution of Cu followed same declining pattern with deeper soil depths, across the tillage systems. Similar beneficial effects of CA on micronutrient content were observed by several other researchers (Wright *et al.* 2007, Shukla *et al.* 2017). The decomposition of fresh crop residue under CA provided organic tissue bound micronutrients, as well as natural chelating agents like citric acid, humic acids which in turn enhance the availability of micronutrients in the soil (Shukla *et al.* 2017).

Yield of kharif maize: Tillage and cropping systems were the main factors which affected productivity and soil health. The maize grain yield under ZT and PB was statistically at par (5.49-5.55 t/ha) but it was significantly greater than CT (4.81 t/ha). The maize yield was higher by 15.3 and 14.1% under ZT and PB, respectively over CT. Higher productivity of different crops under CA was owing to improvement in nutrient availability and other soil health parameters (Choudhary *et al.* 2019, Amit-Kumar *et al.* 2018). Under different cropping systems, the highest

productivity was recorded in MCS followed by MWmb, MMuMb and MMS with values ranging from 5.17 to 5.81, 4.84 to 5.72, 4.71 to 5.52, 4.51 to 4.95 t/ha, respectively across the tillage practices. It may be explained due to inclusion of double legumes in MCS (narrow C:N ratio crop residue) increases the rate of decomposition of crop residues and enhancement of soil microbial activity and available nutrients in soil which leading to better growth of the crop and ultimate the productivity (Raghvendra *et al.* 2017, Amit-Kumar *et al.* 2018).

Relationship between maize grain yield and available macro- and micronutrients: Yield was positively correlated with all the parameters except Fe and Cu and it showed negative correlation with soil pH (Table 3). The NH₄⁺ was positively correlated with NO₃⁻, P, K, S and Mn also the positive correlation among P, K, S, Fe, Mn, and Zn has been observed. The available S also showed positive correlation with micronutrient (Table 3). All the micronutrients had a significant positive correlation among themselves (Shukla *et al.* 2017).

This study examined the effect of 7 years of CA-based practices *vis-à-vis* CT in a long-term field experiment (sandy loam, semi-arid region) on maize yield and soil fertility parameters. Residue retention, inclusion of legumes in cropping systems increased maize yield by 15.3 and 14.1% respectively in PB and ZT over CT under diversified cropping systems such as MWmb and MCS. From the study, it can be concluded that adaptation of CA practices, i.e. permanent bed (PB) along with residue retention in maize-based cropping systems could sustain maize productivity and soil fertility in arid and semi-arid regions of India.

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