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Impact of conservation agriculture on potassium fractions under maize based cropping systems in a *Typic Haplustept*

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ABSTRACT

Intensive conventional tillage practice has deteriorated soil quality and decreased potassium (K) availability in soil under maize-based growing areas in Indo-Gangetic Plain of India. Consequently, maize productivity has declined over the years demonstrating the need for sustainable alternatives. A present study was carried out in 2018-2019 in the eleventh year of an on-going long-term experiment initiated in the year 2008 to understand the impact of different tillage practices on K dynamics under maize-based cropping systems in Inceptisols of Indo-Gangetic Plain of India. The experiment was laid out in split plot design with three levels of tillage practice as main plots: permanent raised bed (PB), zero tillage-flat (ZT-flat) and conventional tillage (CT-flat) and in subplots four different cropping systems viz. maize-wheat-mungbean (MWMb), maize-chickpea-sesbania (MCS), maize-mustard-mungbean (MMuMb), and maize-maize-sesbania (MMS). The result showed that the higher content of water-soluble K, exchangeable K, and nonexchangeable K were recorded in PB and ZT-flat tillage and MCS and MWMb as compared to CT tillage practice and cropping systems. Therefore, PB and ZT-flat tillage and MCS as well as MWMb could be better practices over the CT tillage practice and cropping systems for improving K availability in soil.

Key words: Tillage practices, cropping systems, K dynamics, conventional, tillage

INTRODUCTION

Maize holds a vital position as one of the world's key cereal crops, alongside rice and wheat, contributing to both rural food sources and fodder (Shiferaw *et al.*, 2011). Cultivated across 187 million hectares in 166 countries, it plays a substantial role in global grain production, representing nearly 40% in 2017 (FAOSTAT 2019). In India, maize is grown on approximately 9.6 million hectares, contributing significantly to the national food supply (Dass *et al.*, 2020). Maize demonstrates adaptability to diverse soil and climatic conditions and can be integrated into various crop sequences across multiple agro-ecologies in India, making it a promising choice for crop diversification (Islam, Nath, and Samajdar 2018). Among the cropping sequences, maize-wheat is the third most significant, covering 1.8 million hectares, primarily in rainfed regions. Other prominent maize-based systems in India include maize-mustard, maize-chickpea, maize-maize, cotton-maize, and rice-maize, especially in eastern India. However, maize productivity in India lags behind the global average, primarily due to more than three-fourths of maize cultivation being conventional and rainfed, which is highly dependent on the unpredictable South-West monsoon (Dass *et al.*, 2020). Conventional maize farming practices involve intensive tillage, causing detrimental effects on soil quality, which poses a significant challenge for sustainable agricultural production (Nandan *et al.*, 2019; Sharma *et al.,* 2019). These practices are not only resource-intensive but also labor and time-consuming, substantially increasing production costs (Jat *et al.*, 2014). Conservation agriculture is a vital solution to restore and preserve soil quality (Friedrich *et al.,* 2012). Conservation tillage practices, such as zero tillage and permanent raised bed tillage, offer multiple benefits over conventional tillage, including timely sowing, minimal draft power requirements, increased yields, enhanced water use efficiency, and improved soil infiltration and aeration. Zero tillage, for instance, is practiced on about 105 million hectares globally and 3.20 million

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hectares in the Indo-Gangetic Plains (WCCA Report 2009). In the context of maize-based cropping, scarce information is available on potassium (K) dynamics, which is essential, especially in eastern India, where maize is a critical nutrient-depleting crop sequence. Potassium (K) exists in soil in four primary forms: water-soluble K, exchangeable K, non-exchangeable K, and structural or mineral K, all of which are in equilibrium with each other. Water-soluble and exchangeable K forms are readily available to plants, but they constitute a small proportion of the total K content. K dynamics play a pivotal role in maintaining soil K concentration, involving interchanges among these four forms, depending on the K concentration in the soil solution. The quantification of the actual K requirements for plants and the precise application of fertilizer remains a challenge in India, particularly in intensive cropping systems. These systems often experience a negative K balance, with application and removal of K not aligning (Madar *et al.*, 2020). In such scenarios, there is a heightened reliance on nonexchangeable K to meet the K needs of crops

Tillage is one of the management practices which affect the fate of added K to the soil due to soil disturbance and growing crops (Deubel *et al.,* 2011). The aim of the current study is to investigate the effect of tillage practices on K stratification, plant availability, and plant uptake under different tillage systems and cropping systems. The present study generates information on these issues about the forms of K under different tillage practices and maize-based cropping systems in Inceptisols.

METHODS AND MATERIALS

The Indian Institute of Maize Research in New Delhi, India, conducted a long-term field experiment was started since 2008. The site experiences semi-arid conditions with 650 mm annual rainfall and 850 mm evaporation. Soil of experiment is sandy loam and non-saline (EC 0.32 dS m^{-1}) having pH 7.8,. The experiment was arranged in a split-plot design with different tillage practices (PB, ZT, CT) and four cropping system like Maize-wheat-mungbean (MWMb), Maize-chickpea-sesbania (MCS), Maize-mustard mungbean (MMuMb) and Maize-maize-sesbania (MMS). Soil samples from 0-5 cm, 5-15 cm and 15-30 cm depths were collected in 2019 after harvest of summer crops. Soil samples were air-dried, crushed, and soil samples were subjected to the analysis of different soil K fractions. Water-soluble K was extracted using (soil:water :: 1:5) as described by Jackson (1973). Exchangeable K of soil was extracted by shaking neutral normal ammonium acetate for 5 min (1:5) Hanway and Heidel (1952). The HNO_3 extractable K of soil was extracted with 1N boiling HNO_3 1:10 (Wood and De Turk, 1941). The K content in different soil extractants was measured by flame photometrically. Non-exchangeable K was calculated as the difference between boiling HNO_3 K and available K. Total K was estimated by wet digestion of the soil sample with hydrofluoric acid (HF) and perchloric acid ($HClO_4$) as described by Jackson (1967).

RESULT AND DISCUSSION

Tillage and crop establishment methods significantly improve K fractions after eleven years at 0-5, 5-15 and 15-30 cm soil depths. The concentration of water soluble K mainly depends on the weathering in soil, residue retention, clay transformation as well as the past cropping practices that followed. The concentration of water soluble K at all three soil depths (0-5, 5-15 and 15-30 cm) was maximum in PB tillage (36.1, 29.5 and 23.5 mg kg^{-1}, respectively) while the lowest of water soluble K 29.3, 24.2 and 18.0 mg kg^{-1} respectively was recorded in the CT-flat system. The effect of crop rotation on K fractions was also significant at 0-5, 5-15 and 15-30 cm soil depths. The MCS and MWMb plots had the higher levels of WS-K and the values for the two crop rotations were significantly similar for all three soil depths. Among various crop rotations, the lowest WS-K was observed in MMuMb plots 28.7, 23.6 and 9.93 mg kg^{-1} respectively at 0-5, 5-15 and 15-30 cm soil depths (Table 1).

Table 1: Long-term effect of tillage practices and diversified cropping systems on water soluble potassium (mg kg $^{-1}$) in soil under maize based cropping systems

Treatments	0-5 cm	5-15 cm	15-30 cm
	Water soluble potassium		
	Tillage practices		
PB	36.1^{a}	29.5^{a}	23.5^{a}
ZT-flat	32.5^{b}	27.2^{b}	22.0^{a}
CT-flat	29.3^{b}	24.2^{b}	18.0^{b}
LSD=0.05	4.69	3.94	
	Cropping systems		
MWMb	34.9^{a}	28.8^{a}	11.0^{a}
MCS	36.4^{a}	30.3^{a}	11.3^{a}
MMuMb	28.7^{b}	23.6^{b}	9.93^{b}
MMS	30.6^{b}	25.1^{b}	10.2^{b}
LSD=0.05	T	CS	T at same CS and CS at same T
	2.18	1.68	NS

This was due to more residue retention in PB tillage over CT-flat. Exchangeable K is the readily available form of K for the plant. This form remains in dynamic equilibrium with the other forms of K. It mainly depends on the cation exchange capacity of the soil (Deubel *et al,* 2011 and Sharma *et al.*, 2009). Cation exchange capacity was found higher in PB and ZT-flat tillage followed by CT-flat tillage. Therefore, exchangeable K was higher in PB and ZT-flat tillage over the conventional tillage (Table 2).

Table 2: Long-term effect of tillage practices and diversified cropping systems on exchangeable potassium (mg kg $^{-1}$) in soil under maize based cropping systems

Treatments	0-5 cm	5-15 cm	15-30 cm
	Exchangeable potassium		
	Tillage practices		
PB	113^{a}	101^{a}	90.3^{a}
ZT-flat	109^{a}	99.4^{a}	94.2^{a}
CT-flat	95.0^{b}	87.4^{b}	82.0^{b}
LSD=0.05	12.7	11.1	
	Cropping systems		
MWMb	113^{a}	103^{a}	96.0^{a}
MCS	120^{a}	107^{a}	100^{a}
MMuMb	100^{b}	90.0^{b}	78.2^{b}
MMS	91.0^{b}	83.4^{b}	80.8^{b}
LSD=0.05	T	CS	T at same CS and CS at same T
	9.33	7.12	NS

The results are coinciding with the finding of Lakaria *et al.*, 2012). Long-term CA practice had a significantly substantial impact on the K fraction, increasing non-exchangeable K (Table 3). Long-term CA practices increased non-exchangeable K fraction significantly from 1514 to 1259, 1436 to 1177 and 1298 to 1128 mg kg^{-1} respectively under PB tillage practices at 0-5,5-15 and 15-30 cm soil depths over CT flat. The Fe-P was significantly lower in PB than CT at 0–5 and 5–15 cm soil depths. The tillage practices PB and ZT flat were statistically on par with non-exchangeable K at 0-5, 5-15 and 15-30 cm soil depths. MCS displayed the highest non-exchangeable K, demonstrating comparability to MMS and surpassing MMuMb at all soil depths. Non- exchangeable K is not the immediately available form of K for plants. After a long run during growing period, it is the important source of K. The root system of chickpea removes more amount of this form of K than maize and wheat due to which there was higher amount of available K in dry matter of chickpea (Katyal *et al.*, 1987) that ultimately release in larger amount nonexchangeable K in PB and ZT-flat tillage under MCS and MWMb cropping system because of favorable environment of decomposition than the MMuMb and MMS cropping systems in conventional tillage (Table 3).

Table 3: Long-term effect of tillage practices and diversified cropping systems on non-exchangeable potassium (mg kg $^{-1}$) in soil under maize based cropping systems

Treatments	0-5 cm	5-15 cm	15-30 cm
	Non-exchangeable potassium		
	Tillage practices		
PB	1514^{a}	1436^{a}	1298^{a}
ZT-flat	1438^{a}	1349^{a}	1332^{a}
CT-flat	1259^{b}	1177^{b}	1128^{b}
LSD=0.05	166	141	
	Cropping systems		
MWMb	1453^{a}	1374^{a}	1382^{a}
MCS	1548^{a}	1472^{a}	1343^{a}
MMuMb	1350^{b}	1258^{b}	1180^{b}
MMS	1262^{b}	1178^{b}	1108^{b}
LSD=0.05	T	CS	T at same CS and CS at same T
	97.9	104	NS

The carbon dioxide and organic acids release from the decomposition of residues particularly legumes may acts on minerals of soil causes more release of nutrients in soil solution (Deubel *et al.,* 2011). The amount of total K depends on mineralogy of the soil as well as long period of intensive cultivation. Eleven years of continuous cultivation was not able to affect their amount in the soil system (Table 4).

Table 4: Long-term effect of tillage practices and diversified cropping systems on total potassium (mg kg $^{-1}$) in soil under maize based cropping systems

Treatments	0-5 cm	5-15 cm	15-30 cm
	Total potassium		
	Tillage practices		
PB	19968	18513	17470
ZT-flat	19437	18326	17647
CT-flat	18129	17380	15992
LSD=0.05	166	141	
	Cropping systems		
MWMb	19508	18314	17276
MCS	19803	18634	17530
MMuMb	18846	17763	16749
MMS	18554	17579	16590
LSD=0.05	T	CS	T at same CS and CS at same T
	NS	NS	NS

Therefore, non-significant change was observed in the total K among tillage practices and cropping systems. Similar finding has been reported by Singh and Singh (2001). Surprisingly, the interaction between tillage practices and cropping systems did not yield any significant effects on fractions of potassium. This implies that the individual impacts of tillage practices and cropping systems on fractions of potassium are more pronounced than any combined effects resulting from their interaction.

It may be concluded that among tillage practices and cropping systems, PB and ZT-flat tillage practices and MCS as well as MWMb were found to be best crop establishment method and cropping system for improving forms of K availability in Indo-Gangetic plain resulted better crop growth environment and ultimately sustained maize yield.

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