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Long term effect of conservation agriculture in maize rotations on total organic carbon, physical and biological properties of a sandy loam soil in north-western Indo-Gangetic Plains

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ABSTRACT

Maize-based crop rotations are advocated as alternate to rice-based systems in South Asia due to better suitability for diverse ecologies, higher yields with less water use and more palatable maize fodder compared to rice, and increased demand of maize from piggery and poultry industries. Alternate tillage and crop establishment practices are important management strategies for tackling the issues of soil health deterioration and over exploitation of underground water resources, particularly in rice based intensive crop rotations. The conservation agriculture (CA) based tillage and crop establishment practices such as zero tillage (ZT) and permanent raised beds (PB) hold potential to enhance soil organic carbon (SOC), physical and biological properties for sustainability of soil health. Therefore, a long term study was conducted to evaluate the twelve combinations of tillage practices (03) and irrigated intensive maize based crop rotations (04) on organic carbon, physical properties and microbial biomass and enzymatic activities of a sandy loam (Typic Haplustept) soil in north-western India. The tillage practices consisted of ZT, PB and conventional tillage (CT) in main plots and four diversified intensive maize based crop rotations (MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbaina*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*) in sub plots. In this study we analysed the SOC, physical and biological properties of soil at various depths after 7 years of continuous ZT, PB and CT in diversified maize rotations. Compared to CT plots, the soil physical properties like water stable aggregates (WSA) > 250 μm were 16.1-32.5% higher, and bulk density (BD) and penetration resistance (PR) showed significant ($P < 0.05$) decline (11.0–14.3 and 11.2–12.0%) in ZT and PB plots at 0–15 and 15–30 cm soil layers. The soil organic carbon (SOC) increased by 34.6-35.3% at 0–15 cm, and 23.6-26.5% at 15–30 cm soil depths with conservation agriculture (ZT and PB) based crop establishment techniques over CT. Similarly, the soil microbial biomass carbon (MBC) under CA based systems increased by 45–48.9% in 0–30 cm profile depth of a sandy loam (Typic Haplustept) soil. Significant ($P < 0.05$) improvement in soil enzymatic activities i.e., Fluorescein diacetate, dehydrogenase, β Glucosidase and Alkaline phosphatase was also recorded in the CA based treatments. Significant ($P < 0.05$) synergistic effects of summer legumes (mungbean and *Sesbania*) with winter legume/cereal in crop rotations were observed on SOC,WSA, BD, PR and K_{sat} at 0–15 and 15–30 cm depths. Interaction between tillage and crop rotations were significant ($P < 0.05$) for soil organic carbon, physical properties and enzymatic activities. Thus our long-term study suggests that CA based crop management with selected diversified maize based rotations (MCS and MWMb) can be

Abbreviations: ALP, alkaline phosphatase activity; BD, bulk density; BG, ß Glucosidase activity; CA, conservation agriculture; CT, conventional tillage; DHA, dehydrogenase activity; FDA, Fluorescein diacetate hydrolysis activity; GMD, geometric mean diameter; ICAR, Indian Council of Agricultural Research; IGP, Indo-Gangetic Plains; K_{sat}, saturated hydraulic conductivity; MBC, microbial biomass carbon; MCS, maize (*Zea mays* L.)-chickpea (*Cicer arietinum* L.)-sesbaina (*Sesbania acculata*); MMuMb, maize (*Zea mays* L.)-mustard (*Brassica juncea*)-mungbean [*Vigna radiata* (L.) Wilczek]; MMS, maize (*Zea mays* L.)-maize (*Zea mays* L.)-sesbania (*Sesbania acculata*); MWMb, maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-mungbean [*Vigna radiata* (L.) Wilczek]; MWD, mean weight diameter; PB, permanent raised bed; PR, soil penetration resistance; SCL, sandy clay loam; SOC, total soil organic carbon; SL, sandy loam (Typic Haplustept); WSA, water stable aggregates; ZT, zero tillage.

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advocated as sustainable intensification strategy in light textured soils of north-western India and other similar agro-ecologies of South Asia.

1. Introduction

Tillage is an important management practice involving physical manipulation of soil for crop establishment. Optimization of tillage practices lead to improvement in soil health. Soil health is a dynamic and complex system, and its functions are mainly mediated by agricultural management practices (Doran and Zeiss, 2000). Intensive agricultural practices often leads to changes in soil health governing properties like, soil structure, aggregation, porosity, strength, hydraulic conductivity, infiltration, bulk density, soil moisture content, soil carbon content, microbial biomass and their activities (Osunbitan et al., 2005; Allen et al., 2011). Soil with better health and quality will be able to produce higher crop yield under favourable as well as extreme climatic conditions (Congreves et al., 2015), and soil health acts as a critical component for adaptation and mitigation of climate change effects by the crops (Congreves et al., 2015). Therefore, long term study (>5 years) on effect of tillage practices for maintaining or enhancing soil physical, chemical and biological characteristics of sandy loam (Typic Haplustept) soil are needed (Singh et al., 2016). However, measurement and demonstrations of soil health related properties (physical, chemical and biological), and their interactions are very complex (Karlen et al., 2003).

Sandy loam (Typic Haplustept) soil is the most dominant soil texture of Indo Gangetic Plains. The main production constraints of this type of soil are higher bulk density, poor water retention capacity, higher hydraulic conductivity, lower soil organic carbon and lower biological activities (Singh et al., 2016). The low organic carbon content in sandy loam (Typic Haplustept) soils is one of the major reasons for declining in soil health resulting in low and unsustainable productivity of intensified irrigated rice-wheat cropping systems of this region (Dwivedi et al., 2003; Singh et al., 2005). However, the other drivers for replacing of rice-wheat system with maize based crop rotations are (i) better adaptability of maize crop because of its C_4 nature, (ii) increasing demand of maize for poultry, piggery and fishery sectors, (iii) narrowing export market for rice (Dass et al., 2012; Pandey et al., 2008), (iv) higher productivity potential with more palatable fodder of maize. These factors recently compelled the Government of India to put a major emphasis on diversification of rice with maize especially in dark zones (areas where water table is declining due to overexploitation of ground water resources) of the rice-wheat rotation across north-western Indo-Gangetic Plains (IGP). However, as a futuristic strategy, there is a need to study the long-term consequence of contrasting tillage & crop establishment practices in diverse maize rotations on soil health for designing future action plan in these ecologies.

Crop management practices (tillage systems or cropping sequences) can affect soil health. Karlen et al. (2013) observed that deep soil ploughing with mouldboard plow had significant negative impact on soil health and quality parameters. Some studies showed encouraging findings of increasing soil organic matter, soil structure due to maintenance of soil aggregates, reduced oxidation of soil organic matter with minimum tilling of soil compared to conventional tillage (Beare et al., 1994; Halvorson et al., 2002). Similarly, diversification in crop rotations can also affects soil health by affecting carbon contents, due to the difference in chemical composition of different crop residues that are added to soil (Srinivasarao et al., 2013). These effects of either tillage or cropping systems on soil physical and chemical properties affect the microbial biomass and their activities and some other important processes such as organic matter decomposition and mediation of plant nutrient availability (Dick, 1992; Balota et al., 2003). However, precise information on the long term effects of different tillage practices and intensified maize based crop rotations on soil health in the IGP region of South Asia is lacking. The research findings of this region and elsewhere presents an opportunity to investigate the effect of long term agricultural management systems on soil health parameters.

It is hypothesized that conservation agriculture based tillage practices (ZT and PB) and diversified maize based crop rotations improve soil physical, chemical and biological properties and overall soil health, compared to conventional tillage and existing dominant rice-wheat cropping system of the region. Identification of best tillage practice and/or crop rotation to maintain or enhance soil health can help the farmer/grower to plan their crop

Table 1
Initial status (prior to wet season, 2008) of soil properties at f the experimental site.

A. Soil Physical properties

Soil Properties	Depth (cm)					
	0–10	10–20	20–30	30–40	40–50	50–60
BD ($Mg\,m^{-3}$)	1.58	1.64	1.73	1.73	1.73	1.72
PR (kPa)	805	1600	1810	2060	2049	1965

B. Carbon and aggregation

Depth (cm)	SOC ($g\,kg^{-1}$ of soil)	WSA (%)	MWD (mm)	GMD (mm)	K_{sat} ($cm\,h^{-1}$)	Particle size distribution			Soil Texture
						Sand (%)	Silt (%)	Clay (%)	
0–15	4.40	55	0.830	0.595	0.919	64.10	16.84	19.25	SL
15–30	4.21	51	0.700	0.539	0.875	64.45	10.75	24.84	SCL
30–45	3.70	48	0.598	0.528	0.703	63.89	10.15	26.24	SCL

C. Soil biological properties

Depth (cm)	MBC $\mu g\,C\,g^{-1}$ soil	FDA μg Floresceing $g^{-1}\,h^{-1}$	Dehydrogenase μg TPF Rel $g^{-1}\,day^{-1}$	ß Glucosidase μg *p*-NP Rel g^{-1} 24 h^{-1}	Alkaline Phosphatase μg *p*-NP Rel g^{-1} 24 h^{-1}
0–30 cm	340	0.445	22.38	1.56	39.0