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Changes in soil biology under conservation agriculture based sustainable intensification of cereal systems in Indo-Gangetic Plains

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ABSTRACT

Continuous rice-wheat (RW) rotation with conventional agronomic practices has resulted in declining factor productivity and degrading soil resources. A farmer's participatory research trial was conducted in Karnal, India to evaluate 8 combinations of cropping systems, tillage, crop establishment method and residue management effects on key soil physico-chemical and biological properties. Treatments (T) 1–4 involved RW and 5–8 maize-wheat (MW) with conventional tillage (CT) and zero tillage (ZT) with (+R) and without (−R) residue recycling. Residue was either incorporated (R*i*) or mulched (R*m*). Treatment 1 (RW/CT − R) had the highest bulk density (BD) (1.47 Mg m^{-3}) and T8 (MW/ZT + R*m*), the lowest (1.34 Mg m^{-3}). After 3 years of cropping, soil accumulated more organic C in (a) MW (9.33 Mg ha^{-1}) than RW (8.5 Mg ha^{-1}), (b) ZT (9.25 Mg ha^{-1}) than CT (8.58 Mg ha^{-1}), and (c) + R (10.18 Mg ha^{-1}) than –R (7.65 Mg ha^{-1}). MW system with ZT and residue (T8: MW/ZT + R*m*) registered 208, 263, 210 and 48% improvement in soil microbial biomass C (MBC) and N, dehydrogenase activity (DHA) and alkaline phosphatase activity (APA), whereas RW system in T4 (RW/ZT + R*m*) registered 83, 81, 44 and 13%, respectively as compared with T1 (RW/CT − R), the business as usual scenario. Treatment 8 (MW/ZT + R*m*) recorded the highest microbial population viz. bacteria, fungi and actinomycetes. The most abundant micro-arthropods present in the soil of experimental plot were *Collembola, Acari* and *Protura* which varied with treatments. Soil MBC, APA, BD and micro-arthropod population were identified as the key indicators and contributed significantly towards soil quality index (SQI). MW system with ZT and R*m* (T8) recorded the highest SQI (1.45) followed by T6 (1.34) and the lowest score (0.29) being in T1 (RW/CT − R). The SQI was higher by 90% in MW compared to RW, 22% in ZT compared to CT, and 100% in residue recycling compared with residue removal. System yield was strongly related to key soil quality indicators and also positively correlated with SQI. Longer-term studies are essential to realize maximal effects of improvements in soil health on crop yields.

1. Introduction

The Indo-Gangetic Plains (IGP) in India, the cradle of Green Revolution (GR) covers about 20% and 27% of the total geographical and net cultivated area, respectively and produces about half of the food consumed in the country (Dhillon et al., 2010). Rice-wheat (RW) system is the lifeline of millions of food producers and consumers in IGP. With the advent of GR, the RW system, has so far, successfully maintained the balance between food supply and population growth. This was possible with the use of improved seeds, chemical fertilizers, irrigation and farm mechanization along with expansion of area under cultivation. However, resource intensive RW production system has caused negative environmental externalities and second generation problems such as groundwater depletion, soil health degradation and

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loss of nutrients through emission and leaching, declining factor productivity and shrinking farm profits (Chauhan et al., 2012). Due to these negative effects of the production practices, productivity of RW system has plateaued or even declined, posing a threat to the sustainability of this important cropping system (Bhatt et al., 2016).

To address the aforementioned challenges, conservation agriculture (CA, based on the principle of minimal mechanical disturbance of soil and permanent organic soil cover coupled with efficient crop rotations) has been a subject of intensive scientific investigation for cropping system management studies (Ladha et al., 2016; Sithole et al., 2016). Zero-tillage (ZT) has been an attractive strategy for wheat farmers to facilitate early planting, lower production cost and increase yield so as to increase overall productivity and profitability (Nawaz et al., 2017). With the development of “Turbo Happy Seeder” that can directly drill seed and fertilizer through the previous crop residue (Sidhu et al., 2015), farmers of IGP are also retaining crop residue and gradually moving towards full CA-based RW systems. Further, to address the problem of water and labour shortages, maize-wheat (MW) system is emerging as an alternative to RW system due to less water and labour requirement of maize than rice (Gathala et al., 2014). Over the last decade, several researchers have reported the effect of different tillage, residue management and cropping sequences on agronomic productivity (Jat et al., 2014), nutrient- water- and energy-use-efficiency (Devkota, 2011; Gathala et al., 2014), soil physical properties (Alam et al., 2017), greenhouse gas (GHG) emissions (Sapkota et al., 2015), economic profitability (Nawaz et al., 2017), adapting to climate risks (Jat et al., 2016) and overall sustainability (Ladha et al., 2003) of the systems. To our knowledge, effect of these improved management practices on soil fauna, flora and associated soil biological activities and processes is scanty. Food and Agriculture Organisation (FAO) gives slogan of ‘*Healthy soils for healthy life*’ during ‘International Year of Soils-2015’ and laid emphasis on sustainable management of soils which can be possible only by knowing health of soil by assessing its quality (http://www.fao.org/soils-portal/en/).

Soil organisms play major role in improving soil health and can be used as an important soil quality indicator (Doran and Zeiss, 2000). Soil productivity primarily depends on its biological health, which includes the magnitudes of microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), and enzymatic activities. Microbes function as agents of transformation of organic matter, nutrient cycling, and energy flow among other functions (Six et al., 2004) that impinge on sustainability. Soil microbial biomass and enzyme activity have been suggested as potential indicators of soil quality because of their relationship to soil biology, and rapid response to changes originated by management and environmental factors (Mohammadi, 2011). In soil biota, micro-arthropods are considered to be one of the very important biotic components of soil ecosystem being involved in decaying organic material and thereby increase its availability for micro-organisms and to stimulate nutrient turnover (Petersen et al., 2002).

Alterations in tillage, residue recycling, and crop rotation practices induces significant changes in the quantity and quality of plant residue entering the soil, their seasonal and spatial distribution, the ratio between above- and below-ground inputs and nutrient dynamics, all of which influence soil microorganisms and soil microbial processes (Govaerts et al., 2007). In arable soils, micro-arthropods depend on the input of crop and root residues or organic manures as source of food whereas, the amount and quality of organic input is decisively determined by the agronomic management interventions (Sapkota et al., 2012).

Individual soil parameters alone may not be sufficient for decision making regarding sustainability of the cropping system (Mandal et al., 2005). Soil quality index (SQI) is an important tool to access the suitable combination of soil properties. The higher values of SQI denote the better quality of soil to perform in better way to produce at higher and sustainable level. Indexing of soil quality under different soil and crop management practices is important for identifying the critical key indicators of soil health (Mandal et al., 2005). Throughout the globe, researchers used different parameters and techniques for estimation of SQI under different situations (Doran and Jones, 1996; Lima et al., 2013; Mandal et al., 2005; Masto et al., 2007; Mohanty et al., 2007; Sharma et al., 2005; Stott et al., 2013; Yao et al., 2013). In CA based management systems in IGP, studies on various soil parameters especially physico-chemical properties and few reports on biological properties have been documented but in isolation. Comprehensive information on soil quality indexing using all parameters (physico-chemical and biological) in CA-based management systems and their relationships with crop yield is very limited. Thus, this study was aimed to identify key soil quality indicators under different conservation agricultural management practices. We hypothesize that higher SQI would result in maize–based cropping system with CA than without CA-based maize and in rice-based cropping system with CA than non-CA rice. Overall, maize–based cropping system with CA would lead to higher SQI than rice-based cropping system. Therefore, the present study was carried out to assess the influence of CA-based management practices such as tillage, crop establishment method, residue management and crop rotation on soil quality improvement in rice and maize based cropping system in North-western IGP.

2. Materials and methods

2.1. Study site

A farmers' participatory field experiment was set up during monsoon 2012 at Tarawari village of Karnal district in Haryana, India (29°48′ N; 76°55′ E). Climate of the region is semi-arid sub-tropical with extreme weather conditions with hot and dry to wet summers (May–October) and cool, dry winters (November–April). The average annual temperature is 24°C and average annual rainfall is 670 mm, 75–80% of which is received during southwest monsoon (July to September). The soil type is Typic Ustocrept. Before start of the experiment, the study site has clay loam soil (Sand 32%, Silt 30%, Clay 38%) with slightly alkaline reaction (pH 7.94) and EC (0.44 dS m^{-1}). Oxidizable organic carbon at 0–15 cm soil layer was 0.44%. The field had low available nitrogen (alkaline permanganate fraction; 146.8 kg ha^{-1}), medium available phosphorus (Olsen P; 15.0 kg ha^{-1}) and exchangeable potassium (ammonium acetate extract; 241.86 kg ha^{-1}).

2.2. Experimental treatments and agronomic management

The field experiment was laid-out in randomized block design with three replicates of each eight cropping system treatments varying in crop sequence, tillage and residue management. The plot size was 20 m × 5.4 m and the distance between plots and blocks was 1.0 and 1.5 m, respectively. A summary of the treatment details is presented in Table 1.

2.3. Soil sampling and analysis

After three cropping system cycles (2012–2015), soil samples were collected from surface layer (0–10 cm) randomly from five places within each plot by using a soil auger (5 cm internal diameter) after harvesting of wheat in summer 2015. Five samples within a plot were thoroughly mixed to make a composite sample. The initial soil properties (pH, EC, organic carbon and available N, P, K) were also measured from air dried samples. Soil pH and electrical conductivity (EC) in soil: water ratios of 1:2 were determined by following standard methods (Jackson, 1973). The oxidizable soil organic carbon (SOC) was determined using wet oxidation method (Walkley and Black, 1934), available N by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (Olsen P) by ascorbic acid reductant method (Olsen et al., 1954) and available potassium (K) by flame