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# Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems

Madhu Choudhary[a], Hanuman S. Jat[b,*], Ashim Datta[a], Arvind K. Yadav[a], Tek B. Sapkota[b], Sandip Mondal[c], R.P. Meena[d], Parbodh C. Sharma[a], M.L. Jat[b]

[a] ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, India
[b] International Maize and Wheat Improvement Centre (CIMMYT), India
[c] Indian Statistical Institute, Giridih, Jharkhand, India
[d] ICAR-Indian Institute of Wheat and Barley Research (IIWBR), Karnal, India

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ABSTRACT

Monotonous rice-wheat cropping system with conventional management practices have resulted in declining soil quality and biota in addition to low input factor productivity and farmer's profitability in western Indo-Gangetic plains (IGP) of India. Conservation agriculture (CA) based sustainable intensification (SI) is required to improve the soil quality while improving the productivity and profitability. A field experiment was conducted to evaluate the effects of CA based management practices such as zero tillage (ZT), direct seeding of rice (DSR), crop diversification, residue recycling and legume integration for SI in comparison to conventional management on soil quality and biota in cereal (rice and maize) based cropping systems. Fourteen treatments were included in which four treatments ($T_1$–$T_4$) with rice–wheat and two treatments ($T_{11}$–$T_{12}$) with maize-wheat system were based on conventional management, while six treatments ($T_5$–$T_{10}$) with rice–wheat and two ($T_{13}$–$T_{14}$) with maize-wheat were based on CA management practices. Conservation agriculture based SI of maize-wheat-mungbean ($T_{14}$) recorded lower soil bulk density (1.33 Mg m$^{-3}$). Soil organic carbon (OC) was increased by 83% and 72% with CA based rice-wheat-mungbean ($T_{10}$) and maize-wheat-mungbean ($T_{14}$) system, respectively and it was at par with $T_9$ and $T_{12}$ compared to farmer's practice ($T_1$) (4.6 g kg$^{-1}$). Mean microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were 213% and 293% higher with $T_{14}$ over $T_1$ (646 and 201 µg g$^{-1}$ dry soil), respectively. However, $T_{10}$ recorded 117% and 171% higher MBC and MBN, respectively compared to $T_1$. Dehydrogenase activity (DHA) and alkaline phosphatase activity (APA) were improved by 210% and 49% under $T_{14}$; 140% and 42% under $T_{10}$ compared to $T_1$ (180 µg TPF g$^{-1}$ soil 24 h$^{-1}$ and 144 µg p-nitrophenol g$^{-1}$h$^{-1}$), respectively. Mean number of bacteria, fungi and actinomycetes were increased by 28%, 68%, 98% respectively, under $T_{14}$ relative to $T_1$, and at par with $T_{12}$ and $T_{10}$. Most abundant micro-arthropod group belonged to *Collembola* followed by *Acari* and *Protura*, irrespective of treatments. Higher soil quality index (SQI) was observed in $T_{10}$ (0.82), followed by $T_{14}$ and $T_6$ treatment (0.76). Sustainable intensification of rice and maize based systems ($T_{10}$ and $T_{14}$) recorded 39% higher system yield compared to $T_1$ (11.12 Mg ha$^{-1}$). CA-based sustainable intensification of rice/maize systems improved soil quality and biota, hence resulted higher system yield in alluvial soils of IGP. Conservation agriculture based SI of maize-wheat-mungbean system was found to be the best alternative option than rice–wheat system to achieve sustainable productivity while improving the soil quality index (35%) and conservation of natural resources.

## 1. Introduction

Rice-Wheat cropping system is the cornerstone of India's food security and is most widely prevalent not only in India but in entire South Asia. This cropping system occupies about 13.5 million hectares in the Indo-Gangetic Plains (IGP), of which 10 million hectares are in India, 2.2 million hectares in Pakistan, 0.8 million hectares in Bangladesh and 0.5 million hectares in Nepal (Mahajan and Gupta, 2009). During

*Abbreviations:* APA, Alkaline phosphatase activity; BD, Bulk density; CA, Conservation agriculture; CT, conventional tillage; DHA, Dehydrogenase activity; EC, Electrical conductivity; EMI, Eco-Morphological Index; IGP, Indo-Gangetic Plains; MBC, Microbial biomass carbon; MBN, Microbial biomass nitrogen; MDS, Minimum data set; OC, Organic carbon; QBS, Biological soil quality; ZT, Zero tillage

* Corresponding author at: CIMMYT-India, CG Block, National Agriculture Science Center (NASC) Complex, Pusa, New Delhi 110 012, India.
*E-mail address:* h.jat@cgiar.org (H.S. Jat).

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"Green Revolution" in mid-sixties, good quality inputs such as quality seed, chemical fertilizers and assured irrigation facilities remarkably enhanced the productivity of this system. However, nowadays conventional tillage (CT) based practices have proved to be insufficient in meeting the challenges of enhanced and sustained productivity and halting the natural resource degradation. Besides this, global warming also warrants the need to change conventional practices to reduce greenhouse gas emissions (You et al., 2005) from rice-wheat system.

Indiscriminate use of ground water exploitation for irrigation purposes mainly for growing rice made the situation worse in western IGP (Punjab, Haryana and western Uttar Pradesh). Conservation agriculture (CA) with proven principles of minimum soil disturbance, rational surface cover with efficient crop rotation has been introduced with the aim of conserving natural resources (soil, water and energy) (Sharma et al., 2015). More recently, maize has been introduced in lieu of Crop Diversification Program of Government of India in western IGP to replace 5% of rice area due to its lesser (only 10–15% of rice) water requirement, equal production potential and minimum support prices (MSP). The positive effects of CA-based options resulted in higher crop yields, water saving, labour use and soil health improvement in cereal based systems (Gathala et al., 2013; Jat et al., 2015). In addition, system intensification through integration of short duration mungbean (*Vigna radiata*) may provide an opportunity to increase the farmer's profit (Kumar et al., 2018).

Adoption of practices that minimize soil impacts is fundamental to agricultural sustainability as soil environment is affected by returning of plant residues which affect soil structure, temperature, moisture and aeration, which, in turn, affect soil quality and biota. Soil biota directly and indirectly impacts soil ecosystem services that can affect its productivity (Barrios, 2007). The magnitude of microbial biomasses like carbon, nitrogen, phosphorus and enzymatic activities reflects biological health of soils which governs soil productivity (Hussain et al., 2009; Kawabiah et al., 2003). Microbes plays an important role in the transformation of organic matter, nutrient cycling, and energy flow (Six et al., 2004; Wardle and Giller, 1996) which significantly impact the sustainability of the system. Microbial activities have been used to measure the influence of soil management practices on soil quality (Kabiri et al., 2016). In soil not only microbes but meso and macrofauna also plays an important role in the determination of soil quality (Baretta et al., 2014). Microarthropods are considered important soil biotic component that helps in increasing organic matter availability for microbes through decomposition of crop residues or organic materials present in soil (Petersen and Luxton, 1982). Amount and quality of organic input like green manuring and crop rotation have shown the impact on the population densities of microarthropods (Frampton and van den Brink, 2002).

There is lot of literature available on productivity, profitability and resource use efficiency under CA and CT based cereal systems of western IGP (Kumar et al., 2018; Singh et al., 2016). Many studies had conducted on improvement in soil properties (Bhattacharyya et al., 2015) and nutrient availability (Jat et al., 2017). Hardly there were any study on a series of CA-based cropping system treatments and their influence on soil biological parameters and SQI. Recently in another experiment Choudhary et al. (2018) studied the effect of different CA-based rice-wheat and maize-wheat cropping systems on improvement in soil quality index and observed the higher efficiency of CA-based maize-wheat system in soil quality improvement over rice-wheat system. However, paucity of literature is available on layering of CT vs CA based sustainable intensification management practices on soil quality and soil biota in cereal systems. We hypothesize that CA-based rice-wheat and maize-wheat system with mungbean integration would result improved soil quality index and productivity over others. Among these two systems, maize-wheat-mungbean would lead to higher SQI than rice-wheat-mungbean. Therefore this present study was, undertaken i) to assess the soil quality and soil biota using varied indicators under a series of CA and CT based crop management practices and also ii) to analyse their influence on the system yield. Through linear contrast analysis, we identified different combinations of systems and studied their interaction effect on individual soil properties.

## 2. Materials and methods

### 2.1. Study site

In 2012, a field experiment was set up at Taraori, Karnal, India (Lat. 29°48′N and Long. 76°55′E) in farmer's participatory mode on sustainable intensification of cereal systems by International Maize and Wheat Improvement Centre (CIMMYT). Semi-arid and sub-tropical climate prevails in the experimental area with hot, dry to wet summers (May-October) and cool, dry winters (November-April). The average annual temperature and rainfall are 24 °C and 670 mm, respectively of which 75–80% is received normally during southwest monsoon (July to September). Temperature (maximum and minimum) and rainfall of the study period are presented in supplementary figure (Fig. S1). Soil texture was clay loam (sand 32.08%, silt 29.64%, clay 38.28%) having a soil pH and EC of 7.94 and 0.44 dS $m^{-1}$ in 1:2 suspension of soil water, respectively. The soil is Typic Ustocrept. Soil organic carbon content was 0.47 ± 0.04%. The experimental soil was low in available nitrogen (146.8 kg $ha^{-1}$), medium in available phosphorus (15.0 kg $ha^{-1}$) and potassium (242 kg $ha^{-1}$).

### 2.2. Treatments and experimental design

Experiment was arranged in randomized block design with fourteen treatment combinations ($T_1$–$T_{14}$) varied in crop sequence, tillage, establishment method, residue management, mungbean integration and other management practices. Treatments were based on conventional and conservation agriculture management systems of rice and maize based cropping systems of western IGP. The treatments were designed on different drivers of agricultural changes adopted by the farmers of western IGP. Each plot size was 20 m × 5.4 m. A description of treatment details are presented in Table 1.

### 2.3. Recycling of crop residues

Entire above ground residues of wheat and rice were removed or retained as per the treatment description given in Table 1. All the residues from $T_1$, $T_2$, $T_5$ and $T_6$ (rice-wheat system), and $T_{11}$ (maize-wheat system) were removed. Full residue (100%) of rice, anchored residue of wheat (33%) and maize (50%) were retained or incorporated as per the description given in Table 1 in the remaining treatments. Higher amount of crop residues were retained in $T_{10}$ (30.95 t $ha^{-1}$) followed by $T_{14}$ (29.75 t $ha^{-1}$), $T_{12}$ (28.59 t $ha^{-1}$) and $T_4$ (26.50 t $ha^{-1}$) over 3 years.

### 2.4. Soil sampling and analysis

Soil samples were collected from surface layer (0–10 cm) of all three replicates of each treatment from five locations by auger (with 5 cm diameter) after the harvesting of wheat crop (April) in 2015. Within replicate, a composite sample was prepared. A part of the soil samples were dried in shade, ground and passed through 2-mm sieve and analysed for different soil physico-chemical properties viz., pH, electrical conductivity (EC), organic carbon (OC) and available N, P, K. Fresh soil samples were passed through 2-mm sieve and analysed for different soil biological properties viz., microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial count, dehydrogenase activity (DHA), alkaline phosphatase activity (APA). Soil pH and electrical conductivity (EC) in soil: water ratio of 1:2 was determined by following Jackson (1973). Soil bulk density (BD) was measured by core sampler method (Blake and Hartge, 1986). The oxidizable organic carbon (OC) was determined using wet oxidation method (Walkley and