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Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice–wheat cropping system

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ABSTRACT

Information about the changes in soil properties upon change in the agricultural management system is essential for sustainability of the system. The long-term (15 years) impact of zero tillage in wheat under rice–wheat cropping system in semi-arid region of Indo-Gangetic Plains (IGP) was evaluated for physical properties, organic carbon build up, root growth and wheat productivity in different textured soils. The conventional (CT, two harrowing, one cultivator and planking) and zero tillage (ZT, direct drilling) systems were investigated.

ZT increased soil organic carbon significantly to a depth of 0.10, 0.15 and 0.25 m in sandy loam, loam and clay loam soil, respectively, indicating its buildup to deeper depths with increase in fineness of soil texture. Carbon stock in surface 0.4 m soil depth increased by 19.0, 34.7 and 38.8% over CT in 15 years in sandy loam, loam and clay loam soil, respectively. The corresponding carbon sequestration rates were 0.24, 0.46 and 0.62 Mg ha^{-1} year^{-1}. It reduced the plough pan, however, a significant increase in bulk density was observed in surface 0.05 m in sandy loam and 0.10 m in both loam and clay loam soils. Water dispersible silt + clay reduced indicating better soil aggregation. Saturated hydraulic conductivity increased significantly only to a depth of 0.10 m but with varying magnitudes. Increase in magnitude in surface 0.05 m layer was highest in loam (51%) followed by sandy loam (40%) and clay loam (38%) soil. Although ZT increased water retention and aeration porosity but increase in field water capacity was significant to a deeper depth (0.15 m) in clay loam soil. Water intake rate also increased significantly in clay loam soil (28%) over CT. The root biomass increased significantly and the highest increase was recorded in loam (81%) followed by sandy loam (70%) and clay loam (42%) soil. In addition, ZT encouraged roots to penetration deeper in the soils.

In spite of improved soil physical properties and root growth under ZT, the significant increase in mass of grains and consequently the wheat yield, was observed only in clay loam soil indicating that the physical properties of other soils under CT have not reached to a stage limiting plant growth and yields. Study concludes that the ZT practice in wheat under rice–wheat system of semi-arid region of IGP in Haryana may be adopted for sustaining productivity of the system but the implementation of the practice must be promoted in fine textured soils.

1. Introduction

Information about soil properties under different agricultural management systems is essential for sustainability of the systems. The rice–wheat cropping system which is critical for food security in South Asia, occupies approximately 13.5 Mha of land, extending across Indo-Gangetic Plains (IGP) covering Pakistan (2.2 Mha), India (10.5 Mha), Bangladesh (0.8 Mha) and Nepal (0.5 Mha) and plays an important role in providing livelihood to millions of people (Timsina and Connor, 2001). In India, it is the most important cropping system and stands first in coverage. The system covers 23% of rice and 40% of wheat, and both crops together contribute 85% of the total cereal production contributing substantially to national food basket (Katyal et al., 1998). Being remunerative, this cropping system has become popular even in light textured soils. The system is primarily irrigated and 85% is concentrated in the IGP. A significant increase in productivity of this system has been achieved during Green Revolution due to introduction of high yielding and disease resistant crop varieties, increased use of inorganic fertilizers, better irrigation facilities, improved weed and pest control measures, better farm machineries and implements, etc. Recent evidences from long-term

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experiments, however, showed that increase in yield is slowing down and sometimes even declining (Ladha et al., 2003). Monoculture rice–wheat system for several decades and contrasting soil physical and hydrological requirements of these two cereal crops require high intensity of tillage operations. As a consequence, there has been degradation of soil and water resources threatening the sustainability of the system in Inceptisols and Alfisols of IGP (Gupta et al., 2003) and Vertisols (Mohanty et al., 2007) of the country. Efforts for diversification of agriculture and adoption of alternative cropping systems could not be successful due to assured profitability and lower risks with the system. Keeping in view the importance of rice–wheat system, resource conservation technology in the form of zero-tillage (ZT) was introduced in the region during 1996–97. The main emphasis has been to reduce or eliminate tillage in wheat to reduce the turn-around time and cost of cultivation (Mehla et al., 2000). It was rapidly adopted occupying an estimated area of 0.82 Mha in the Indian IGP during 2003–2004 including the area under reduced tillage (Laxmi et al., 2007). But, as per latest information available, some farmers now discontinued ZT due to the perceived need for occasional tillage, soil compaction and weed control; some use the ZT drill but maintain a limited degree of tillage while some continue to use ZT and conventional tillage side by side on the same farm (Erenstein et al., 2007). This emphasises the need to understand the interactions between ZT and soil type, seasonal factors and cumulative effects that cause farmers to adhere to conventional or reduced tillage in some areas. It is evident that the influence of tillage systems on soil properties and crop yield is controlled by the type of soil, climatic conditions, cropping history, etc. (Mahboubi et al., 1993; Halvorson et al., 2002), therefore, worldwide literature on soil properties and crop performance of ZT systems is inconsistent and even contradictory. Erenstein and Laxmi (2008) compiled and reviewed the research work related to ZT in the rice–wheat system in the IGP and reported ZT as successful, particularly, in northwest India but to a lesser extent in the Indus plains in Pakistan. Most studies focused on timely planting of wheat, controlling the weed *Phalaris minor*, reducing cost of production and water savings without giving much emphasis on changes in soil physical and biological properties taking place continuously inside the soil which may affect the plant system in the years to come. Moreover, long-term soil management strategies require integrated research on the root-zone limitations including surface and sub-soil rather than surface 0.15 m soil alone, which is quite lacking in literature. Therefore, the present study was undertaken to evaluate the long-term impact of zero-till wheat in rice–wheat cropping system on soil physical properties, organic carbon buildup, root growth and wheat productivity parameters in three texturally different soils of semi-arid region in IGP of Haryana State (India).

2. Materials and methods

2.1. Site characteristics and soil

The study was conducted at three sites at farmers' fields in Haryana State (27°39′–30°55′ N, 74°27′–77°36′ E) under semi-arid climatic conditions where long-term tillage experiments are being conducted in rice–wheat cropping system. Sites were located in village Pirthala of Fatehbad, Uchana of Karnal and Teek of Kaithal district of the State. The soils of the area are derived from Indo-Gangetic alluvium and are classified as fine loamy, deep, mixed hyperthermic Typic haplustepts by Soil Taxonomy. The soils at Pirthala, Uchana and Teek are sandy loam, loam and clay loam, respectively, and normal in pH and salt contents, low in available N, medium to high in available P and K (Table 1). The three textures of soil represent soils under rice cultivation in the entire State of Haryana.

Table 1
Physico-chemical properties of surface soil (15 cm) of the experimental sites.

Property	Site		
	Pirthala (Fatehbad)	Uchana (Karnal)	Teek (Kaithal)
Sand (%)	70.6	61.3	46.7
Silt (%)	12.8	20.1	21.9
Clay (%)	16.6	18.6	31.4
Textural class	Sandy loam	Loam	Clay loam
$pH_{(1:2)}$	7.8	8.0	8.1
$EC_{(1:2)}$ dS m^{-1}	0.66	0.48	0.52
Organic carbon (g kg^{-1})	4.5	5.8	6.6
Available N (kg ha^{-1})	106	121	108
Available P (kg ha^{-1})	17	16	26
Available K (kg ha^{-1})	226	238	158

2.2. Tillage treatments and soil sampling

The long-term experimental sites were initiated during 1996–97. The fields (0.4 ha) under zero-tilled (ZT) wheat for the last 15 years and adjoining continuously conventionally cultivated (CT) wheat under rice–wheat system were selected for monitoring the changes in physical properties, organic carbon build up, root growth and wheat productivity. In ZT field, the residues of the rice harvested by combine harvester were left on the surface and wheat was sown with zero till machine while in CT, the residues of rice were manually removed and seed bed tilth for wheat was prepared by two discing to about 0.1 m followed by planking (leveling with a 3 m long wooden bar) of the fields. The fields under both the tillage treatments were continuously puddled during *kharif* season and under cultivation for the last several decades. Five plots of 1 m × 1 m were randomly selected in each tillage treatment at all the three sites, and bulk and core samples were obtained at 0.05 m interval starting from the surface to 0.4 m depth at harvest of the wheat crop (PBW 550) during *rabi* season of 2011–12. A total of 240 samples were collected for determining various physical properties of soil.

2.3. Measurement of soil properties

The soil organic carbon content was determined by Walkley and Black (1934) method. Depth-wise soil bulk density was measured by core method (Blake and Hartge, 1986) and the moisture content was determined gravimetrically. Carbon stock and carbon sequestration rate were calculated from the values of organic carbon content and bulk density at different depths of the soils. Infiltration rate of soil was determined by using infiltrometers (Bouwer, 1986). Water dispersible silt + clay contents were obtained as ratio of per cent silt + clay content of soil dispersed in water to its quantity obtained from particle size analysis by International Pipette method (Piper, 1966). For aeration porosity, soil cores were saturated and brought to equilibrium in the hanging water column at a suction of 0.5 m. Volume of water released per unit volume of soil was used as a part of pore space which is filled with air and expressed in percentage as aeration porosity. Field water capacity was determined using pressure plate apparatus at −33 kPa as described by Richards (1954).

2.4. Measurement of root density

Core samples at 0.05 m interval starting from the surface to 0.4 m depth were collected from five places from each of the selected plots at all the sites and roots were separated by keeping the soil cores in the sieve and subsequently removing the soil by slowly applying water. The roots were then dried and their weights were recorded.