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Double no-till and permanent raised beds in maize–wheat rotation of north-western Indo-Gangetic plains of India: Effects on crop yields, water productivity, profitability and soil physical properties

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ABSTRACT

Excessive pumping of groundwater over the years to meet the high water requirement of flooded rice crop and intensive tillage have threatened the sustainability of irrigated rice–wheat system (RWS) in the Indo-Gangetic plains (IGP) of South Asia. Replacement of rice with less water requiring crops such as maize in the RWS and identification of effective strategies for alternate tillage systems will promote sustainable cropping systems in the IGP. To this effect a 3-year field experiment was established with annual maize–wheat rotation in the north-western IGP of India to evaluate the effect of 3 tillage systems (conventional flat, CTF; no-till flat, NTF; permanent raised beds, NTB) on crop production, water use efficiency, economic profitability and soil physical quality. Grain yield of maize was highest (8.2–73.4%) under NTB followed by NTF and CTF across the years. Wheat yield was significantly higher under NTF during the 1st year while tillage practices had non-significant effect in the succeeding two years. On average, maize planted on NTB recorded about 11% lower water use and 16% higher water use efficiency compared to CT. The NTB and NTF required 24.7% and 10.8% less irrigation water than CTF system, respectively with 11.5% higher system productivity and demonstrated higher water productivity. The NTB and NTF systems provided similar net returns (averaged over 3 years) in maize–wheat system (MWS), which were US$ 281 ha^{-1} higher compared to CTF system. The CTF system had higher bulk density and penetration resistance in 10–15 and 15–20 cm soil layers due to compaction caused by the repeated tillage. The steady-state infiltration rate and soil aggregation (>0.25 mm) were higher under NTB and NTF and lower in the CTF system. Similarly, mean weight diameter (MWD) of aggregates was higher under NTF and NTB compared to CTF. The study reveals that NTB and NTF systems could be more viable options for MWS in order to save input costs and enhance profitability; however, the long-term effects of these alternative technologies need to be studied under varying agro-ecologies.

1. Introduction

Maize grown in sequence with wheat is the 5th dominant cropping system of India occupying ~2.0 million ha in Indo-Gangetic Plains (IGP), the heartland of rice–wheat (RW) production system of South Asia (Yadav and Subba Rao, 2001; Jat et al., 2009). The relatively high productivity of the RW system South Asia is occurring at the costs of over-exploitations of natural resources such as water and soil with increasing air pollution. Continuous pumping of groundwater over the years to meet the high water requirement of flooded rice has resulted in a drastic decline in groundwater tables (Humphreys et al., 2010; Sharma et al., 2012) leading to potential reduction in water availability in the future and an increase in socio-economic instability. These detrimental factors have given impetus to pursue alternative crops and cropping systems, which are more environmentally friendly and efficient in utilizing natural resources (Aulakh and Grant, 2008). Maize has a significantly lower irrigation requirement than rice and can enhance the productivity of the system, and sustain soil health and environment quality (Meelu et al., 1979). In the recent past, owing to diminishing

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water availability as well as increasing cost of pumping for rice cultivation coupled with high yielding cultivars of maize, the acreage under maize–wheat system (MWS) has shown increasing trends in north-western India. By 2020, the demand for maize in developing countries will surpass the demand for both wheat and rice and to meet this rising demand, higher maize production is necessary (Srinivasan et al., 2004). Traditionally, maize and wheat are grown by broadcast seeding on flat layout after 6–7 tillage operations and using flood irrigation. The traditional practice of growing these crops is costly and results in inefficient utilization of irrigation water and nutrients leading to low productivity and input efficiency. Conservation agriculture based crop management technologies, such as no-till and permanent raised beds with residue retention and judicious crop rotation, are gaining more attention in recent years with the rising concern over degradation of natural resources, mainly soil and water, and to offset the production cost (Ladha et al., 2009; Jat et al., 2009; Saharawat et al., 2012). Tillage practices contribute greatly to the energy and labour cost in any crop production system resulting to lower economic returns (Labios et al., 1997; Jat et al., 2005; Saharawat et al., 2010; Vivak-Kumar et al., 2013). Furthermore, intensive tillage systems results to a decrease in soil organic matter due to acceleration of the oxidation and breakdown of organic matter and ultimately degradation of soil properties (Biamah et al., 2000; Gathala et al., 2011b). No-till (NTF) system is now being widely used by farmers in many parts of the world. The origin and use of permanent raised beds (NTB) have traditionally been associated with water management issues, either by providing opportunities to reduce the adverse impact of excess water on crop production or to irrigate crops in semi-arid and arid regions (Connor et al., 2003; Sayre and Hobbs, 2004; Bhushan et al., 2008; Gathala et al., 2011a). The NTB with only superficial reshaping in the furrows between the raised beds as needed before planting of each succeeding crop can reduce cultivation costs and increase sustainability of MWS systems (Govaerts et al., 2005). Moreover, it controls machine traffic, limiting compaction to furrow bottoms, allows the use of lower seeding rates than with CTF planting systems and reduces crop lodging (Sayre and Moreno-Ramos, 1997).

The farmers in the IGP of India are yet to grow maize and wheat using a NTF system either on flat or NTB, though it is a common practice in many western countries. Bed planting of maize can help in proper plant establishment, increases input efficiency, increases yields, and opens up avenues for NTF system. Adoption of NTF practice helps in timely seeding of either of the crops, hence leads to increase in productivity. From a preliminary study, Dhadli et al. (2009) reported lower yields of soybean and maize with CTF and NTF compared with NTB on a clay loam due to intermittent flooding observed during monsoon rains, which adversely affected the crop yields in the flat systems. From a 4-year study on sandy clay loam soil in Pakistan, Hassan et al. (2005) reported mean increases of 30%, and 65% in grain yield and water productivity of maize, respectively, under NTB compared to traditional practice. However, Ram-Singh et al. (2012) recently reported similar productivity but higher economic returns from MWS under NTB and NTF compared with CTF on coarse-textured loamy sand soil. Various on-farm participatory trials revealed little or no difference in productivity under NTF compared to best managed CTF maize (Gupta et al., 2002). They further reported that despites the similar yields economic advantage of US$ 50 ha^{-1} saved by farmers in tillage and irrigation costs under NTF maize. More such studies are needed to evaluate NTB and NTF systems over conventional tillage under different soil and climatic conditions. With this in view an experiment was established to evaluate the NTF and NTB vis-a-vis CTF in terms of crop and water productivity, farm income and soil physical health for long-term sustainability of maize–wheat rotation on sandy loam soil in northwestern India.

2. Materials and methods

2.1. Experimental site

The experiment was conducted at the research farm (29°4′N, 77°46′E, and 237-m above mean sea level) of the Project Directorate for Cropping Systems Research, Uttar Pradesh, India, during 2004–2007. Before start of the experiment, the field was under continuous conventional tillage and puddled transplanted rice-conventional till wheat system since past over 6 years. The soil (0–15-cm) of the experimental field was a typic Ustochrept with a sandy loam in texture with pH 8.1, 0.40% organic carbon (Walkley and Black, 1934), 135 kg ha^{-1} alkaline $KMnO_4$ oxdizable N (Subbiah and Asija, 1956), 13 kg ha^{-1}Olsen-P and 165 kg ha^{-1} ammonium acetate extractable-K.

The climate of the area is semi-arid subtropical, characterized by very hot summers and cool winters. The hottest months are May and June, when the maximum temperature reaches 45–46 °C, whereas, during December and January, the coldest months of the year, the temperature often drops below 5 °C. The average annual rainfall is 863-mm, 75–80% of which is received through the north-west monsoons during July to September. Weekly distribution of rainfall, minimum and maximum temperatures, and sunshine hours for the three cropping system years (May–April) are shown in Fig. 1.

2.2. Experimental design and treatments

The three treatments consisting of double no-tillage, permanent raised beds and conventional tillage in a maize–wheat rotation were evaluated in a randomized block design with three replications (see below for treatment details). The each experimental unit consisted of 16.0-m × 8.5-m (136 m^2) plot.

T1. Conventional till drilling of maize and wheat after conventional tillage (CTF). Maize (HQPM-1) was drilled on flat land at 67-cm row and 20-cm plant to plant spacing after conventional dry tillage (three passes of tillage, one with a harrow and two with cultivator followed by planking with a wooden planker). After the harvest of maize, the field was prepared with conventional-tillage (same as for maize) that followed pre-sowing irrigation for sowing of wheat (PBW-343) at 20-cm row spacing.

T2. No-till maize direct drilling of maize and wheat after no-tillage (NTF). Both maize and wheat were directly seeded without any preparatory tillage using the no-till planter seeded without any preparatory tillage using the no-till planter keeping row to row and plant to plant spacing similar to that in T1.

T3. Direct drilling of maize and wheat on permanent raised beds (NTB). At the beginning of the experiment, raised beds were prepared after conventional tillage (as in T1) using a raised-bed planter and were left for 30 days to settle. The beds were 37 cm wide at the top and 15 cm in height and separated by furrows having a 30-cm-wide top (Jat et al., 2009). The distance between the centre to centre of the two adjoining furrows was kept at 67 cm. The maize was directly drilled using a raised-bed planter with 20-cm plant to plant spacing, keeping one row in the centre of the top of the bed. Total plant population (74,627 plants ha^{-1}) was kept similar in the three treatments. After maize, wheat was directly drilled using the same raised bed planter that reshapes the beds along with seeding and fertilizer placement in single operation.

2.3. Crop management

For maize, an inverted T-type furrow opener along with a zero-till planter having an inclined plate seed metering system with fertilizer attachment was used for seeding in all the three treatments. A seed rate of 20 kg ha^{-1} was used and the seed depth