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Evaluation of tillage and crop establishment methods integrated with relay seeding of wheat and mungbean for sustainable intensification of cotton-wheat system in South Asia

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ABSTRACT

Intensive tillage-based conventional cotton-wheat system (CWS) entails high production costs and has low crop and water productivity thereby threatening its sustainability in the north-western India. Conservation agriculture (CA) based management practices such as conservation tillage, permanent raised beds and relay planting have the potential to improve sustainability, profitability, and water use efficiency in CWS. A two-year (2013–2015) field experiment was conducted to evaluate CA based management practices such as zero tillage (ZT), permanent beds, relay seeding (RS) of wheat, seeding configuration, and integration of mungbean (MB) in terms of crop productivity, input use efficiency (water and energy) and profitability in the CWS system. Treatments included; permanent narrow (67.5 cm, PNB) and broad (102 cm, PBB) raised beds with cotton planted in the centre of beds, ZT narrow flats (67.5 cm, ZTNF) and broad flats (102 cm, ZTBF), and PBB with cotton planted on one side of bed and intercropped with MB (PBBc + MB) or no MB (PBBc). In the above treatments, wheat was relay seeded in standing cotton after second picking. In addition, conventional till (CT) CWS on flats was included as control treatment. PBBc + MB produced 37% and 10% higher system productivity (2 yrs' mean) over CT and PBB, respectively. Relay seeded wheat on PBB produced 50% higher yield and required 40% less irrigation water compared to CT wheat in both the years. Mean system irrigation water productivity (WP_I) was 131% higher with PBBc + MB compared with CT. The energy input was 61% higher in CT compared to PBB but energy output was 21% higher with PBB than with CT. PBB and PBBc + MB recorded 52–54% higher energy productivity and 64–69% higher net returns compared to CT. In conclusion, PBB and PBBc + MB were the best options for sustainable CWS under similar soil and climatic conditions in India.

1. Introduction

Cotton (*Gossypium hirsutum* L.)—wheat (*Triticum aestivum* L.) is a well-established crop production system occupying 4.5 M ha in South Asia (SA) including approximately 2.6 M ha in India (Das et al., 2014). In the past decade, farmers realized both high productivity and returns in cotton after the introduction of Bt cotton hybrids even under conventional practices. The CWS requiring significantly less amount of irrigation water is important to diversify unsustainable RWS which requires high inputs of water leading to decline in ground water table at an alarming rate in Northwest (NW) India and many other parts in SA (Yadvinder-Singh et al., 2014a). However, over the time cotton-wheat system (CWS) has started showing a declining trend in crop productivity and profits due to insect-pest infestation, delay in sowing of wheat after cotton, reduced availability of irrigation water, erratic monsoons and poor quality of underground waters (CICR, 2011; Mayee et al., 2008). Conventional land preparation for cotton and wheat involves 4–5 tillage operations for each crop. Generally, wheat sowing after cotton is delayed by 20–30 days beyond the optimum time (1–15 November) due to late pickings in cotton and time involved in subsequent tillage operations for seedbed preparation. The delay in sowing reduces wheat yield by 1.5–2.0 t ha^{-1} compared to timely sown crop (Buttar et al., 2013). Timely sowing of wheat in CWS can be accomplished

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by relay seeding in standing cotton (Khan and Khaliq, 2005; Buttar et al., 2013).

Conservation agriculture (CA)-based technologies (zero (ZT), permanent raised beds, relay seeding and crop intensification) have been advocated for increasing yields, reducing irrigation water input and production costs, and enhancing income and sustainability in different cropping systems in SA (Aryal et al., 2014; Kumar et al., 2013; Buttar et al., 2013; Gathala et al., 2011, 2013; Ladha et al., 2009; Jat et al., 2013, 2014; Ram et al., 2005; Saharawat et al., 2010; Sayre and Hobbs, 2004). Past research showed benefits of broad-beds (≥101 cm) in terms of increase in yields and saving in irrigation water over narrow-beds (≤67.5 cm) in the maize-wheat and CWS. For example, Akbar et al. (2007) reported that there was about 36% water saving for broad-beds and about 10% for narrow-beds compared to flat sowing, and grain yield increased by 6% for wheat and 33% for maize. Devkota et al. (2013) reported that grain yields of wheat and maize after cotton increased by 12 and 42% under PB than under CT, respectively. Under PB, water productivity increased by 27% in wheat and 84% in maize compared to CT in irrigated lands of central Asia. Residue retention on PB increased the grain yield of wheat and maize by 5% and 15% compared to residue removed, respectively. In a 2-year rotation, Naudin et al. (2010) reported that while cotton yields were 12% lower for CT and 24% lower for ZT than for ZT with mulch and one site, cotton yields were similar under the three tillage treatments at the other site. Karamanos et al. (2004) showed that ZT plus residues increased soil water content, cotton root growth and cotton yield compared to CT. Recent study from North India showed that CWS under permanent broad beds + residues provided higher productivity, net returns, and water productivity compared conventional planting (Das et al., 2014). In contrast, a few studies showed significantly lower cotton and wheat yields under ZT than under CT (Tripathi et al., 2007; Jalota et al., 2008). However, profitability increased under reduced tillage, mainly due to 50% less sowing cost compared to CT. Similarly, Afzalinia et al. (2011) reported 15.7% lower seed cotton yield but 77.3% lower fuel consumption under conservation tillage compared to CT. Choudhury et al. (2006) and Yadvinder-Singh et al. (2009) reported that wheat yields in RWS were lower on raised beds compared to flats on coarse-textured soils in the NW Indo-Gangetic plains (IGP). Thus, soil types and climatic conditions may largely influence the adaptability of permanent bed planting systems in different cropping systems.

At present prospectus of developing high-yielding early-maturing cotton cultivars with uniform maturity seems less likely. Therefore, alternate option for timely sowing of wheat lies in relay planting of wheat in CWS (Buttar et al., 2013; Singh et al., 2016). Another approach to increase productivity and profitability could be integration of short-duration (60–70 day-old) mungbean (*Vigna radiata*) in CWS. Since a small window of 15–20 days is available between wheat harvest and cotton planting, intercropping of mungbean (MB) in cotton is possible by modifying planting geometry. MB not only provides additional income but also acts as a break crop and increases N availability in soil through biological fixation (Meelu et al., 1994).

The combinations of relay seeding of wheat in cotton, and MB in cotton combined with ZT or permanent bed planting could provide opportunities for sustainable intensification of CWS in SA. Recently, Singh et al. (2016) have developed 4-wheel high clearance tractor driven relay seeders suitable for both narrow (67.5 cm) and broad beds (101 cm) for relay seeding of wheat in cotton. This new machine with minor modifications has also been successfully used for inter cropping of MB in wheat (H.S. Sidhu, personal communication). At present only a few studies have evaluated CA-based tillage and crop establishment options for CWS in SA. Therefore, present study was conducted to evaluate the effects of CA-based management practices (ZT, permanent narrow and broad beds, relay seeding and integration of mungbean) in a CWS on (i) crop yields and system productivity, and (ii) water productivity, energy use efficiency and net returns. We hypothesized that permanent broad bed planting with relay seeding of wheat and intercropping of MB in cotton would maximize crop and water productivity, and net returns compared with conventional practice in CWS.

2. Material and methods

2.1. Experimental site and soil characteristics

Field experiment on CWS was conducted for two consecutive years (2013–14 and 2014–15) at Borlaug Institute for South Asia (BISA), Ladhowal (30.99°N latitude, 75.44°E longitude and at an elevation of 229 m above mean sea level), Punjab located in Trans-Gangetic alluvial plains of India. Before 2013, the field was under maize-wheat system for the last three years and received recommended mineral fertilization for both crops.

The soil (0–15 cm layer) of the experimental field was sandy loam in texture, with pH 8.17, Walkley-Black organic C 4.3 g kg^{-1}, electrical conductivity 0.22 dS m^{-1}, $KMnO_4$ oxidizable N 127.4 kg ha^{-1}, 0.5 M $NaHCO_3$ extractable P 9.90 kg ha^{-1}, and 1N NH_4OAc extractable K 149.4 kg ha^{-1}. Soil bulk density was 1.40 Mg m^{-3} and infiltration rate measured using double ring infiltrometer was 15.64 mm h^{-1}.

2.2. Climate characteristics

Experimental site represented the sub-tropical climate with hot and dry (May–June) to wet summers (July–November) during the MB/cotton growing season and cool dry winters (December–April) during wheat growing season with mean annual rainfall of 680 mm and nearly 80% is received during the cotton season. The average annual pan evaporation is about 850 mm. May and June are the hottest month (40–44.8 °C), while January is the coldest month (as low as 1.6 °C). Total rainfall received during the growing periods of wheat, cotton and MB was 220.4, 1033.7 and 376.4 mm during 2013–14 and 202.2, 490.9 and 114.8 mm during 2014–15, respectively. Compared to 2014–15, amount of rainfall received during the cotton and MB growing seasons was more in 2013–14 mainly due to 250 mm of rainfall received in week 24 (Fig. 1a). Wheat in 2013–14 experienced lower minimum temperature in the month of January compared to that in 2014–15, while the trend in maximum temperature was reversed during the same period (Fig. 1b).

2.3. Treatments and experimental design

Seven combinations of CA-based tillage and crop establishment (planting method and crop geometry) options include: permanent narrow (67.5 cm) raised beds (PNB), permanent broad (102 cm) raised beds (PBB), ZT narrow flat (ZTNF), ZT broad flat (ZTBF), PBB with cotton planted at alternate side of bed (PBBc) and PBBc intercropped with MB followed by relay seeding of cotton (PBBc + MB). In addition, a CT treatment in both cotton and wheat was also included (Table 1). In bed planting, crops weregrown on the raised beds alternated by furrows. The experiment was laid out in a randomized complete block design with three replications. Fig. 2 shows the configuration of cotton, wheat and MB crops under different treatments. The plot size for each treatment was 450 m^2.

The experiment was set up in the wheat season of 2012–13 and the fresh beds were prepared after CT using bed maker (see details under sub Section 2.5). The permanent beds wereres haped each year after wheat harvest. The reshaping included use of relay seeder attached to high clearance tractor after adjusting the tynes of bed