



Evaluating alternatives to rice-wheat system in western Indo-Gangetic Plains: Crop yields, water productivity and economic profitability

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ABSTRACT

Serious water deficits, diminishing profitability and deteriorating natural resources are threatening agricultural sustainability in many regions of South Asia. High water input and low water productivity of conventional irrigated rice–wheat (RW) systems has led to the depletion of surface water and ground waters in northwest India. Conservation agriculture (CA) practices with precision irrigation management and replacing rice with low water requiring maize crop may help to achieve sustainable crop production in the western Indo-Gangetic Plains (IGP) of India. A three-year field experiment was conducted to evaluate the effect of CA-based management (tillage, crop establishment, residue management mungbean integration), precision water management on crop and water productivity, and economic profitability in RW and maize-wheat (MW) systems. The treatments for RW systems included: i) conventional till rice-wheat with irrigation scheduling at critical growth stages (CTRW); ii) CTRW + mungbean (CTRW + MB); iii) Zero-till RW with residue retention (+ R) scheduling precise irrigation (PI) based on soil matric potential approach (ZTRW + R + PI); and iv) ZTRW + MB + R + PI. A similar set of treatments was evaluated for MW systems, except the crops were established on raised fresh beds (FB) and permanent beds (PB). Treatment PBMW + MB + R + PI recorded 38% higher system productivity, saved 1660 mm of irrigation water, increased irrigation + rainfall water productivity (WP_{I+R}) by 270% and increased net returns by 84% compared to CTRW. ZTRW + MB + R + PI recorded 24, 41 and 37% (3 yrs' mean) higher system productivity, WP_{I+R} and net returns, respectively, compared to CTRW. System productivity was increased by 19 and 33%, WP_{I+R} by 223 and 29% and net returns by 84 and 57% with ZTRW and PBMW compared to CTRW, respectively irrespective of MB integration and residue management. On average, inclusion of MB in cereal systems (RW/MW) contributed an 18% increase in system productivity and a 15% increase in net returns. CA based sustainable intensification of MW systems (PBMW + MB + R + PI) is a better alternative to RW system (ZTRW + MB + R + PI) as it provides opportunities for saving 79% of precious water, enhancing crop and water productivity by 12 and 145%, respectively along with high (34%) economic benefits thereby helping to arrest decline in ground water table in the North-West IGP of India.

1. Introduction

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) (RW) is the dominant cropping system occupying an area of 13.5 M ha in the Indo-Gangetic Plains of South Asia (Gupta and Seth, 2007). High productivity derived from intensive RW systems with conventional

management practices is achieved at the cost of over-exploitation of natural resources (air, water and soil) (Ladha et al., 2003). Since the early 1970s, there has been a steady increase in the depth from surface to groundwater in most of the RW area of North-West (NW) India (Hira, 2009; Rodell et al., 2009). The increase in depth has accelerated from about 0.2 m yr⁻¹ between 1973 and 2001 to about 1.0 m yr⁻¹ between

Abbreviations: RW, rice-wheat; MW, maize-wheat; CA, conservation agriculture; IGP, Indo-Gangetic Plains; CT, conventional-till; ZT, zero-till; MB, mungbean; R, residue retention; PI, precise irrigation based on soil matric potential; FB, fresh beds; PB, permanent beds; WP, water productivity; NW, North-West; PTR, puddled transplanted rice; DSR, direct seeded rice; REY, rice equivalent yield

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2000 and 2006 in central Punjab and parts of Haryana states in India (Humphreys et al., 2010; Yadvinder et al., 2014). In 2009, 103 out of 138 administrative blocks were exploited in Indian Punjab, while 55 out of 108 blocks were overexploited in Haryana (Humphreys et al., 2010). Over exploitation of ground water resources due to high water input and low water productivity (WP) is a major threat to the sustainability of the traditional system of puddled transplanted rice (PTR) production in NW IGP of India (Humphreys et al., 2010; Sharma et al., 2012). Irrigated PTR production requires large amounts of water, with 1 kg of rice requiring 2500 l of water due to losses through evapotranspiration and soil percolation (Bouman, 2009) while maize crop require only 600 l for 1 kg grain. Hence, there is an urgent need to manage water efficiently by using cost-effective and eco-friendly techniques.

Improvements in crop WP and the amount of food produced per unit of water consumed have the potential to improve both food security and water sustainability in many parts of the world (Brauman et al., 2013). Water management by proper irrigation scheduling in combination with better crop management techniques (viz., efficient planting techniques) and surface mulch are potential options to save water and increase WP (Yadvinder et al., 2014). Another option to increase WP lies in pursuing alternative crops and cropping systems, which are more environmentally friendly and efficient in utilizing natural resources (Aulakh and Grant, 2008). Cultivation of high yielding ($> 7 \text{ Mg ha}^{-1}$) maize (*Zea mays* L.) cultivars requiring 80–85% less water while sustaining soil health and environment quality has been advocated to replace PTR in the IGP (Sharma et al., 2015). Maize has emerged as the most produced grain in the World and its production is increasing at twice the annual rate of that of rice and three times that of wheat (Fischer et al., 2014). With the changing economy, increasing wealth and dietary patterns leading to higher consumption of animal based foods and growth in the poultry industry, the demand for maize is likely to increase. Demand and production of maize is increasing more rapidly as compared to other major food commodities. It is estimated that by 2025, India would require 50 MMT maize grain, of which 32 MMT for feed sector, 15 MMT for industrial sector, 2 MMT as food and 1 MMT for seed and miscellaneous purposes. Over this there would be about 10 MMT of export potential also. To achieve the target of 50 MMT, a compound annual growth rate of 8% is required from its current level of 5% (Yadav et al., 2016). In the recent past, the acreage under MW systems has grown, becoming a trend in the NW IGP mainly because of reduced tube well discharge and the increasing cost of pumping ground water for irrigation to PTR.

Irrigation scheduling on the basis of soil matric potential to rice, wheat and maize has been shown to save precious irrigation water and increase water productivity compared to conventional irrigation practices (Yadvinder et al., 2014). In recent years, efforts are increasingly devoted to finding more efficient alternatives of current intensive tillage and crop establishment practices in RW system (Gathala et al., 2011; Ladha et al., 2009; Saharawat et al., 2010). Despite cost-saving benefits on labour and water, low DSR yields discourages farmers from adopting ZTDSR (Bhushan et al., 2007; Ladha et al., 2009; Sharma et al., 2002). Major policy issues like free groundwater use and subsidized electricity for the agriculture sector also discourage farmers from adopting these alternative tillage and crop establishment methods for RW systems in NW India.

The conventional practice of growing crops is input (nutrients, energy and water) intensive resulting in low input use efficiency. Intensive tillage practices contribute greatly to high energy and labour costs, resulting in low economic returns (Aryal et al., 2015; Saharawat et al., 2010; Vivak-Kumar et al., 2013). Zero tillage (ZT) and residue retention – two of three principles of conservation agriculture (CA) with best fit crop management technologies can reduce energy and labour costs while improving the soil (Choudhary et al., 2018) and the environment (Jat et al., 2015; Sapkota et al., 2014). In MW systems, establishment of maize on permanent raised beds (PB) can save

irrigation water and increase WP and crop yields (Hassan et al., 2005; Parihar et al., 2016). Maize planted on PB with residue mulch saved 11–29% of irrigation water and improved WP by 16–25% compared to conventional till system (Jat et al., 2013, 2015).

A fallow period of about 65–70 days is available after the harvest of wheat and before the planting of the next rice and maize crop. Cultivation of short duration pulse crop (e.g. mungbean, *Vigna radiata*) in RW and MW systems during the fallow period helps to increase farmers' profits. Previous research reports suggest that CA-based agro-nomic management options will help to achieve high crop yields, save irrigation water and increase economic benefits (Gathala et al., 2013; Jat et al., 2015). We hypothesized that adopting the principles of CA-based management practices layered with precise irrigation water management would save more water, improve WP and profitability in cereal-based systems compared to fixed growth stages based on application of irrigation water. The current study was therefore, undertaken to evaluate CA based sustainable intensification (tillage, crop establishment, residue management, irrigation scheduling and mungbean integration) of MW system as an alternative to RW system on crop productivity, WP and economic performance in the NW IGP.

2. Materials and methods

2.1. Experimental site

The experiment was conducted for three years in a farmer's field in Taraori village (lat. 29.705749 and long. 76.955496), Karnal, Haryana, situated in the NW IGP of India from 2012 to 2015. The climate in the area is semi-arid subtropical, with an average annual rainfall of 650 mm (75–80% of which is typically received from June to September) (Fig. 1). The site was under a continuous RWS for the last > 30 years before the establishment of the experiment.

At the start of the experiment, soil samples at 0–15 cm depth were collected using an auger of 5-cm internal diameter. The soil samples were mixed thoroughly, air-dried, crushed to pass through a 2-mm sieve and stored in sealed plastic jars before analysis. Soil bulk density was measured to a depth of 15-cm using the protocol of Blake and Hartge (1986). Infiltration rate was measured using a double ring infiltrometer method (Bouwer, 1986). Particle size distribution was determined by particle size analysis (Gee and Baudé, 2006). Soil chemical parameters were measured using the standard methods (Table 1). The soil of the experimental field is clay loam with organic carbon content 0.58 g kg^{-1} and pH 7.9 (Table 1). In May 2010, before the start of the experiment, the entire experimental area was levelled (with zero gradient) using a laser-equipped drag scraper (Trimble™, USA).

2.2. Experimental design and treatments

This experiment was laid out in a randomized complete block design consisting of three replications. Eight treatments included in the study consisted of two cropping systems (rice-wheat and maize-wheat) with four combinations of tillage, crop establishment and integration of mungbean. The eight treatments were conventional till transplanted rice followed by conventional till wheat (CTRW) and irrigation using a conventional approach; CTRW + mungbean (CTRW + MB) and irrigation using conventional approach; zero till dry direct seeded rice followed by zero till wheat (ZTRW) + crop residues (R) and precision irrigation (PI) using a soil matric potential based approach (ZTRW + R + PI); ZTRW + MB + R + PI; conventional till fresh raised beds maize followed by conventional till wheat (FBMW), irrigation using a conventional approach; FBMW + MB and irrigation using conventional approach; permanent raised beds maize followed by permanent beds wheat + R and precision irrigation using a soil matric potential based approach (PBMW + R + PI); and PBMW + MB + R + PI. Treatment notations and description of management protocols are given in Table 2.

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