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Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability

Raj Kumar Jat [a,*], Tek B. Sapkota [b], Ravi G. Singh [c], M.L. Jat [b], Mukesh Kumar [d], Raj K. Gupta [a]

[a] *Borlaug Institute of South Asia (BISA), CIMMYT, Pusa, Samastipur, Bihar 848125, India*
[b] *International Maize and Wheat Improvement Centre (CIMMYT), NASC Complex, New Delhi 110012, India*
[c] *Bihar Agricultural University, Sabour, Bihar 813210, India*
[d] *Rajendra Agricultural University, Pusa, Samastipur, Bihar 848125, India*

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ABSTRACT

Water, energy and labour scarcity, increasing cost of production, diminishing farm profits and uncertain weather events are major challenges faced by the farmers under intensive tillage based conventional rice–wheat (RW) production system of Indo-Gangetic Plains (IGP) in South Asia. To address these challenges, conservation agriculture (CA) based crop management practices are being developed, adapted and promoted in the region. We evaluated agronomical productivity and economical profitability of various combinations of tillage, crop establishment and residue management practices in rice–wheat rotation of Eastern IGP of India: a smallholder, poorly resourced and most vulnerable regions for the climatic variability. The long-term trial was initiated in 2006 having 7 combinations of tillage, crop establishment and residue management in rice–wheat rotation. These consisted of conventional till puddled transplanted rice followed by conventional tilled wheat (CTR–CTW); CTR followed by zero tilled wheat (CTR–ZTW); direct seeded rice followed by wheat both on permanent raised beds (PBDSR–PBW); zero-till direct seeded rice followed by CTW (ZTDSR–CTW); ZTDSR followed by ZTW without residues (ZTDSR–ZTW); ZTDSR followed by ZTW with residues (ZTDSR–ZTW + R) and unpuddled transplanted rice followed by ZTW (UpTPR–ZTW). All these treatments were completely randomized and replicated thrice within a block.

During the initial three years of experimentation, we recorded higher rice grain yield in conventional tillage based rice systems (i.e. CTR–CTW and CTR–ZTW) than in CA based systems (i.e. ZTDSR–ZTW, UpTPR–ZTW). During the fourth and fifth years, the rice yields under CT and CA were comparable whereas sixth year onwards, higher yields were recorded under CA based system than in CT based systems. However, the wheat yield was higher in CA based system right from second year onwards. We observed the lowest wheat yield in the system where preceding rice crop was grown with intensive tillage operations (CTR). RW system productivity was higher in almost all the CA based systems than in the CT based and mixture of CT and CA based systems from the second year onwards. The net returns were always higher in CA based systems than in CT based system although the significant differences were obvious only from fourth year onwards in rice and second year onwards in wheat as well as at the system level. The higher grain yields and economical advantage of CA was realized after 2–3 years as the adaptation of CA based component technologies evolved over the time. In medium term, we found CA based systems to be agronomically and economically superior to CT based systems for rice–wheat rotation in a smallholder production system of Eastern IGP of South Asia. Hence, CA based RW production system is one of the pathways for improving productivity, income and food security while sustaining the natural resources in smallholder production systems of Eastern IGP.

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* Corresponding author. Tel.:+91 9472808566.
E-mail addresses: R.Jat@cgiar.org, rkagron@gmail.com (R.K. Jat).

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1. Introduction

The rice–wheat (RW) cropping systems occupies 13.5 million hectares (m ha) in the Indo-Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan (Gupta and Seth, 2007) and are fundamental to employment, income and livelihood for millions of people in the region. In India alone, RW rotation occupies about 10.5 m ha and contributes about 40% of the country's total food grain basket (Saharawat et al., 2010). With the adoption of high yielding varieties and improved crop management practices, the productivity of RW system in the region was remarkably increased and had ushered into green revolution (GR) primarily in North-Western India. However, the GR gains remained slow in the highly populated and smallholder ecologies of Eastern IGP. The Eastern IGP is characterized as highly populated, small farm holding size, poor input and output marketing infrastructure, poor access to new technologies and frequent climatic aberration (floods, drought and temperature), shorter wheat growing season compared to Western IGP. In this rain dependent agro-ecology, the conventional system of rice planting is intensively dry and wet tillage followed by transplanting of 25–40 days old seedlings and most of the time, farmers are not able to transplant rice seedlings in time which leads to reduced rice yield. Moreover, the conventional rice planting system increases production costs and delays the seeding of succeeding wheat crop. Also the repeated wet tillage operations in rice are not only labour, water, time, energy and carbon inefficient but also destroy soil quality and lead to 8–9% reduction in wheat yield compared to wheat grown after dry direct seeded rice (Kumar and Ladha, 2011). The conventional wheat planting system involves repeated dry tillage to prepare the field followed by broadcasting of wheat seeds which also leads to further delay in wheat seeding by almost a week compared to zero tillage planting.

Because of the shorter growing period coupled with its delayed planting due to above said factors, wheat grain filling stage coincides with high temperature (terminal heat) leading to large yield penalty. Though the application of irrigation water at grain filling stage helps in adapting to terminal heats, most farmers in Eastern IGP do not have economical access to irrigation water and hence wheat suffers with high temperature stress at grain filling with yield losses upto 30% (Malik et al., 2014). Recent trends in energy prices and labour shortages due to its migration to other competing sector (for example manufacturing and Mahatma Gandhi National Rural Employment Guarantee Act), and market volatility with overarching effects of frequent climatic variability further adds to the complexity of challenges in RW production systems of the Eastern IGP. These multiple factors forced farmers to adopt sub-optimal and inadequate management practices to grow rice and wheat that end-up with low productivity and profitability. Therefore, the farmers of the region immediately need technologies that have twin benefits of reducing production costs while enhancing productivity on sustainable basis. To address the challenges of rice–wheat production system described above, conservation agriculture (CA) based alternative tillage and crop establishment methods have been designed and tested in IGP (Malik et al., 2014; Ladha et al., 2009; Jat et al., 2013). However, most efforts in Eastern IGP revolved around zero tillage based wheat production system and hence the potential benefits of CA based management systems have not been realized. Therefore, the complexity of challenges in RW system of Eastern IGP cannot be addressed with commodity focused approach and need a system based holistic management strategy.

The conservation agriculture (CA) is a systems based management optimization involving a paradigm shift from intensive tillage to no or reduced tillage, establishment of permanent organic soil cover with economically viable crop rotation that complement reduced tillage and residue retention and also helps breaking cycles of pest and diseases (FAO, 2013). Experimental evidence from various production environments suggests that CA based management can have both immediate, e.g. reduced production costs, reduced erosion, stabilized crop yield, improved water productivity, adaptation to climatic variability (Hobbs, 2007; Bhushan et al., 2007; Jat et al., 2009; Malik et al., 2014) and long-term benefits, e.g. higher soil organic matter contents and improved soil quality (Gathala et al., 2011b; Kienzler et al., 2012).

However, the magnitude of benefits of CA based technologies tends to be site and situation specific and cannot be overly generalized across farming systems (Hobbs, 2007). Based on evidences largely from Africa, Giller et al. (2009) cautioned that CA should not be construed as a "silver bullet" towards achieving the economical, ecological and social dimensions of sustainable agriculture production, but rather judged on merits in different agro-ecological conditions. There is no universal template for CA based management and production practice, and actual practices employed for CA always require a process of refinement and localization to optimize system performance in different environments (Kienzler et al., 2012). For example, even within the IGP, wheat planting window in rice–wheat system is relatively shorter in Eastern Indo-Gangetic Plains (EIGP) than Western Indo-Gangetic Plains (WIGP) and therefore yield penalty due to delayed planting is more in EIGP than in WIGP. Given this difference and wide diversity in agro-ecological conditions, CA based cropping system should be designed for and tested in specific location in order to have significant adoption (Ladha et al., 2009). To our knowledge, no long-term studies have been done to design and test CA based cropping system for Eastern IGP. Therefore, a long-term trial was established in 2006 to design and test various combinations of tillage and crop establishment methods based on CA suitable for smallholder systems of Eastern IGP. In this paper, we analyze, compare and present medium-term effect of CA based practices on system productivity, yield trends and economical sustainability in a rice–wheat rotation.

2. Materials and methods

2.1. Study site characteristics

Experimental field is located at research farm of Rajendra Agricultural University, Samastipur, Bihar, India (25.58,510N, 85.40,313E). The long-term trial was established during monsoon 2006 involving various combinations of tillage, crop establishment and residue management practices in a rice–wheat rotation. The soil of the experimental site is clay loam with medium organic matter content (0.68%). The soil properties of the experimental field at the start of experiment are presented in Table 1. The climate of the site is characterized by hot and humid summers and cold winters with an average annual rainfall of 1344 mm, 70% of which is received between July to September (Fig. 1).

Table 1
Basic soil properties and nutrient status of study site (0–15 cm depth).

Soil properties	Value
Soil texture	Clay loam
pH	8.6
OC (%)	0.68
Available N (mg kg^{-1})	111.96
Available P (mg kg^{-1})	14.02
Exchangeable K (mg kg^{-1})	60.49