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# Conservation agriculture in irrigated intensive maize-based systems of north-western India: Effects on crop yields, water productivity and economic profitability

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ABSTRACT

In north-western India, maize-based systems are being advocated as an alternative to rice-based systems to address the issues of resource degradation, particularly declining water tables and climate-change-induced variability in rainfall and temperature. Conservation agriculture (CA) based *best-bet* crop management practices may increase crop and water productivity, while conserving and sustaining natural resources. In a 6-year study of conservation agriculture experiment established in 2008, we have evaluated the performance of CA-based management practices [permanent bed (PB) and zero tillage (ZT)] and conventional till (CT) for four intensified irrigated maize systems [maize-wheat-mungbean (MWMb), maize-chickpea-*Sesbania* green manure (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-*Sesbania* (MMS)]. Significant ($P < 0.05$) tillage and cropping system interactions were observed for system productivity. Agronomic performance (yield attributes) of all the crops (except wheat) grown in sequence with maize was maximum with ZT, however wheat outperformed on PB over ZT and CT. In the initial two years, higher system productivity (maize equivalent yield) was recorded in PB (8.2–8.5 Mg ha$^{-1}$), while from third year onwards ZT registered maximum productivity (11.3–12.9 Mg ha$^{-1}$).The system glucose equivalent yield increased by 0.6 Mg ha$^{-1}$ under ZT and PB compared to CT. Economic profits from maize-based rotations were invariably higher either in MMuMb or MWMb systems, while in terms of glucose equivalent yield, MMS and MWMb rotation were highest. Synergistic effects of summer legumes (mungbean and *Sesbania*) after winter legume/oilseed/cereal were observed on yield of individual crop *vis-a-vis* system productivity and irrigation water use. ZT and PB practices reduced the irrigation water requirement by 40–65 ha-mm and 60–98 ha-mm, respectively compared to CT system, resulted enhanced system water productivity by 19.4% equally under both ZT and PB. Net profit from the maize-based systems under ZT was up to 31% higher with 72$ ha$^{-1}$ lower production cost compared to CT. Results from our study showed that adoption of CA based tillage practices in MMuMb and MWMb system for sustainable increase of crop and water productivity in north-western region of India.


*Abbreviations:* IGP, Indo-Gangetic Plains; ICAR, Indian Council of Agricultural Research; CA, conservation agriculture; TCE, tillage and crop establishment; ZT, zero tillage; PB, permanent bed; CT, conventional tillage; MWMb, maize (*Zea mays* L.) -wheat (*Triticum aestivum*) -mungbean (*Vigna radiata* L.) Wilczek; MCS, maize (*Zea mays* L.) -chickpea (*Cicer arietinum* L.) - sesbaina (*Sesbania acculata*); MMuMb, maize (*Zea mays* L.) - mustard (*Brassica juncea*) -mungbean (*Vigna radiata* L.); MMS, maize (Zea mays L.) -maize (*Zea mays* L.) -sesbania (*Sesbania acculata*); HQPM, high quality protein maize; GEY, glucose equivalent yield; MEY, maize equivalent yield.

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## 1. Introduction

Rice-wheat (RW) cropping system in north-west India, although providing food security in the country, have also led to soil degradation and over exploitation of underground water resources (Hobbs and Gupta, 2004; Sharma et al., 2012). Furthermore, conventional crop management practices for RW system entail high production costs (Jat et al., 2014) and are highly inefficient in the use of inputs (Saharawat et al., 2010). The diversification of RW systems with maize-based systems and alternate soil and crop management practices could help enhance the system productivity, sustain soil health and environmental quality (Meelu et al., 1979), and save irrigation water and labour costs (Aulakh and Grant, 2008), provide palatable fodder and meeting increased demand of maize grains from piggery and poultry industries (Singh et al., 2016).

Maize, an important crop for food and nutritional security in India, is grown in diverse ecologies and seasons on an area of 8.71 m ha with production of 22.26 mt (GoI, 2015). India Rank 4th in maize area in the world. Maize grain is mainly used for feed (63%), food (23%) and industrial purpose (13%) in the country (Yadav et al., 2014). To meet the rising demand, a quantum jump in maize production is the need of the hour (Srinivasan et al., 2004). In the previous decade (2003–04–2012–13), the maize area expanded by 1.8% and production increased by 4.9% showing productivity growth at 2.6% per annum in India (GoI, 2015). In the past, maize was evaluated as an alternate crop to rice with conventional management practices in RW system, but it was not proved economical due to its lower yield and market price. However, in recent years with the introduction of single cross high yielding and energy-use efficient maize hybrids provided genotypic options for crop diversification in RW systems. In the northwestern Indo-Gangetic plains (IGP) maize is commonly grown in rotation with wheat, chickpea, mustard and winter maize. Another option to improve soil health and increase farmer's profits lies in the integration of short-duration legumes for grain and green manuring (e.g. mungbean and *Sesbania*) in a cereal-based cropping systems (Yadvinder-Singh et al., 2011). Each of these crops in the maize-based system have differential energy requirements (ranging from 1.3 to 2.4 kg kg$^{-1}$ of storage organ) to produce the unit amount of grain/seed (Penning de Vries et al., 1979). Thus, higher yields per unit of substrate can be achieved only by energetically efficient storage organs like cereals compared to oilseeds and pulses. Though economics based calculations preferred from profitability point of view, but bioenergetic production potential in terms of the glucose equivalent yield (GEY) is more appropriate to compare diverse crop based rotations.

Conventional crop production technologies are not much cost-effective (Jat et al., 2014), less water efficient (Bhushan et al., 2007) and cause decline in soil health (Jat et al., 2013) compared to conservation agriculture (CA) practices. Earlier studies showed that CA based management practices are effective for increasing crop and water productivity, and economic sustainability in different cropping systems (Jat et al., 2013, 2014; Das et al., 2014). Similarly, adoption of permanent raised bed planting has been found to enhance crop and water productivity, and reduce the cost of cultivation in RW and other cropping systems (Hobbs and Gupta, 2000; Govaerts et al., 2007; Gathala et al., 2011; Ladha et al., 2009). The area under ZT planting of wheat has increased to more than 2 million ha during 2004–05 in the IGP of South Asia (Rice Wheat Consortium, 2006). The adoption of late duration rice cultivars in IGP results in delayed wheat planting and yield reduction due to heat stress (Chauhan et al., 2007). The adoption of shorter duration maize hybrids compared to rice could be a better option under this situation to reduce over exploitation of natural resources and the production costs and minimize adverse environmental impacts (Ladha et al., 2009; Jat et al., 2009; Saharawat et al., 2012).

Precise information is, however lacking on the potential benefits of CA in irrigated maize-based systems integrated with legumes in the IGP of South Asia. We hypothesized that CA based tillage practices (ZT and PB) and inclusion of legumes in intensified maize based crop rotations may enhance the crop and water productivity, economic profit and improve soil health, compared to conventional tillage. Against this backdrop, the objectives of present study were to evaluate the comparative performance (crop and water productivity, and net returns) of maize-wheat-mungbean (MWMb), maize-mustard-mungbean (MMuMb), maize-maize-*Sesbania* (MMS) and maize-chickpea-*Sesbania* (MCS) cropping systems under different tillage and crop establishment techniques in sandy loam soil of north-west India.

## 2. Material and methods

### 2.1. Description of experimental site and climatic conditions

A long-term field experiment established in June 2008 under a set of tillage and crop establishment (TCE) treatments in four irrigated intensive maize-based cropping systems at the research farm (28°40′N, 77°12′E and 228.6 m elevation) of the Indian Council of Agricultural Research (ICAR)-Indian Institute of Maize Research (IIMR), New Delhi, India. The experiment was conducted on the same layout with same set of treatments and crop varieties/hybrids (except wheat variety PBW 343 was replaced with HD 2967 in the sixth year), and similar management practices over the years (Supplementary Table 1). The climate of the area is semi-arid, with an average mean annual rainfall of 650 mm (70–80% of which is received during July-September) with the mean annual evaporation of 850 mm. Annual rainfall of the cropping cycles (July to June) ranged from 532.8 to 1507.1 mm. The mean daily minimum temperature ranged from 0 to 4 °C in January and mean daily maximum temperature ranged from 40 to 46 °C in May-June (Supplementary Table 2). Mean values of rainfall and, minimum and maximum temperatures recorded at the experimental farm during *kharif* (July-October), winter/*rabi* (November-April) and summer (May-June) seasons are presented in Figs. 1–3. The detailed of the weather parameters of the study period are presented in Supplementary Table 2.

Soil sub-samples were collected at the start of experiment in June 2008 from 0 to 30 cm layer using auger of 5.0 cm diameter. The soil of experimental site was sandy loam in texture, very deep (> 2 m) having 64.1% sand, 12.6% silt and 23.4% clay with pH 7.8, EC 0.32 dS m$^{-1}$, $KMnO_4$ oxidizable N 158.4 kg ha$^{-1}$ (Subbiah and Asija, 1956), 0.5 M $NaHCO_3$ extractable P 11.6 kg ha$^{-1}$ (Olsen et al., 1954), and 1 N $NH_4$ OAC extractable K 248.4 kg ha$^{-1}$, diethylenetriamine penta acetic acid (DTPA) extractable Zn (1.6 mg kg$^{-1}$), Fe (6.7 mg kg$^{-1}$) and Cu (1.3 mg kg$^{-1}$). Depth wise soil organic carbon (SOC) content is given in Supplementary Table 3.

### 2.2. Experiment treatments and design

The experiment was conducted with three main-plot treatments consisting TCE practices [zero tillage (ZT), permanent bed (PB) and conventional tillage (CT)] and four intensified maize-based systems [MWMb, maize (*Zea mays* L.)-wheat (*Triticum aestivum*)-mungbean (*Vigna radiata* L.) Wilczek; MCS, maize (*Z. mays* L.)-chickpea (*Cicer arietinum* L.)-*sesbaina (Sesbania acculata)*; MMuMb, maize (*Z. mays* L.)-mustard (*Brassica juncea*)-mungbean (*V. radiata* L.); MMS, maize (*Zea mays* L.)-maize (*Z. mays* L.)-*sesbania (S. acculata)*] in sub-plots. The experiment was laid out in split-plot design with three replications. Each experimental unit was randomized and consisted of 16.5 m × 4.0 m plots. The details of treatment are summarized in Table 1.

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