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Research Paper

Effects of precision conservation agriculture in a maize-wheat-mungbean rotation on crop yield, water-use and radiation conversion under a semiarid agro-ecosystem

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ABSTRACT

In recent years, water resources have decreased and water saving has become an important issue in the Indo-Gangetic Plains (IGP) of South Asia. Maize-wheat-mungbean (MWMb), is an alternate to traditional rice-wheat cropping system, can mitigate the effects of the frequency, intensity, and duration of rainfall due to climate change on food security in the semi arid-region of north-western IGP. The objective of this research was to determine the productivity, water-use efficiency (WUE) and incident radiation conversation efficiency (IRCE) of MWMb cropping system under 3 tillage practices [zero tillage (ZT), permanent beds (PB) and conventional tillage (CT) and 4 nutrient management strategies [Control (unfertilized), farmers' fertilizer practice (FFP), recommended dose of fertilizers (Ad-hoc) and a site specific nutrient management (SSNM" using the Nutrient Expert® decision support tool). Results of multi-year trial showed that among tillage practices, ZT and PB practices reduced the system irrigation water requirement by 140–200 mm ha^{-1} and 200–300 mm ha^{-1} respectively, compared to CT system, resulting an enhanced grain yield by 5.7–24.6%, biomass yield by 4.6–20.8%, WUE by 18.4–39.0%, and IRCE by 9.9–34.4%, respectively. Significant ($P \leq 0.05$) improvement in system WUE, grain and biomass yield, and IRCE (by 30.6–59.9, 38.3–80.5, 34.3–64.7 and 13.5–48.5%, respectively) was observed in SSNM compared to the unfertilized plots. Significant ($P \leq 0.05$) interactions between tillage practices and nutrient management strategies was measured with respect to water–use, WUE, grain and biomass yield, and IRCE of MWMb system. Combinations of ZT/PB practices + SSNM/Ad-hoc nutrient management strategies registered significantly ($P < 0.05$) higher system WUE and IRCE, grain and biomass yield compared to CT + unfertilized/FFP. Results of present study showed that SSNM/Ad-hoc based nutrient application coupled with CA-based tillage practices in MWMb system has complementarity to attain higher system productivity, WUE and IRCE compared to the use of these crop management practices in isolation.

1. Introduction

Concerns of multiple challenges of sustainability in rice-wheat (RW) rotation vis-à-vis natural resource degradation in north-west IGP are well documented (Saharawat et al., 2010; Chauhan et al., 2012; Singh et al., 2016) especially the rapidly falling water tables (Yadvinder-Singh et al., 2014; Sharma et al., 2012) and the deteriorating soil health (Parihar et al., 2016a). Diversification of rice with maize in the conventional RW system could help in enhancing crop productivity (Gathala et al., 2013), water-use efficiency (Parihar et al., 2016a,2016b), save irrigation water and labour costs (Gathala

Abbreviations: Ad-hoc, recommended dose of fertilizer; CA, conservation agriculture; CT, conventional tillage; FFP, farmers' fertilizer practice; ICAR, Indian Council of Agricultural Research; MWMb, maize (*Zea mays* L.) - wheat (*Triticum aestivum*) - mungbean (*Vigna radiata* L.) Wilczek); NE-Nutrient Expert®, PB permanent beds; IRCE, incident radiation conversion efficiency; SSNM, site specific nutrient management; WUE, water-use efficiency; ZT, zero tillage.

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et al., 2013; Aulakh and Grant, 2008), and may achieve higher radiation-use efficiency (Sinclair and Muchow, 1999). However, conventional crop management practices entail high production costs (Gathala et al., 2013; Jat et al., 2014a) and are inefficient in water and incoming radiation-use (Fahong et al., 2004; Slattery and Ort, 2015; Gitelson and Gamon, 2015; Schneider et al., 2016).

The Indo-Gangetic Plain (IGP) of India, covering about 44 Mha, is dominated by irrigated cereals-based cropping sequences, of which maize–wheat (MW) rotation is the third most important (1.86 Mha) after rice–wheat and cotton–wheat (Jat et al., 2014a,2014b). India is the world's largest user of irrigation water supplied from ground water (Aeschbach-Hertig and Gleeson, 2012). In India and many parts of the world, the irrigation and fresh water resources are increasingly scarce every year due to extensive subsidies and limited regulations (Postel et al., 1996; Vorosmarty et al., 2000; Haddeland et al., 2014). Considering this scenario, we can expect that water resources will be less available for irrigated agriculture and competition for water will increase in the near future in this region. Within this context, a large increase in water-use efficiency is required to optimize agricultural productivity while reducing pressure on natural resources (Tilman, 1999; Gleick, 2003; Rockström et al., 2007; Teixeira et al., 2014). In this sense, alternative best crop management options like conservation agricultural practices which include zero tillage and permanent beds have demonstrated potential benefits on crop yield and profits while saving water, energy and restoring soil degradation across diverse ecologies (Jat et al., 2013, 2014a; Das et al., 2014). Yield is a complex quantitative trait and greatly influenced by modification in external environment, which results in scale or rank shift in its performance (Dia et al., 2016a, 2016b, 2016c, 2016d, 2017).

Recent studies have shown that permanent bed (PB) planting was suitable for enhancing crop productivity and reducing the production cost as well as to conserve the natural resources (Lichter et al., 2008). It also allowed the maintenance of uniform permanent soil cover for higher moisture/water capture and conservation (Govaerts et al., 2005, 2007a). Direct planting of crops in zero tillage (ZT) and PB plots, with balanced fertilization lead to favourable alterations in soil water aggregates (Parihar et al., 2016a,2016b), total porosity (Jemai et al., 2013), maintaining soil and moisture content (Govaerts et al., 2007a,2007b; Sharma et al., 2011) and, as a consequence, it improved plant water availability (Bergamaschi et al., 2010; Jemai et al., 2013). Conservation agriculture (CA) based (zero tillage and permanent bed) crop establishment practices (generally depends upon three basic principles *viz*; minimal soil disturbance, rational soil cover and crop rotation) also improve soil infiltration (Bhattacharyya et al., 2006; Nielsen et al., 2009), water retention (Datiri and Lowery, 1991) and hydraulic conductivity (Benjamin, 1993; Dia et al., 2009; Parihar et al., 2016a). CA-based ZT system could provide additional nutrients (Blanco-Canqui and Lal, 2009; Kaschuk et al., 2010), improve soil physical health (Jat et al., 2013; Singh et al., 2016), better water-use efficiency (Govaerts et al., 2009) and improve nutrient use efficiency (Unger and Jones, 1998). A healthy soil is capable of producing higher crop yield under favourable as well as extreme climatic conditions (Congreves et al., 2015). Reduction in soil disturbance (tillage) and provision of optimum crop nutrition can enhance dry matter accumulation and improve plants metabolic activities, resulting in better yield, leaf area index (LAI) and crop architecture due to plant x environment interactions (Norman and Campbell, 1989). The absorption of solar radiation depends on leaf area index (LAI) and crop architecture (Plénet et al., 2000).

The use of fertilizer nutrients in sub-optimal, optimal and super-optimal doses potentially affects the crop yield and resource use efficiency. Enhanced crop yield, water, and resource use efficiency under balanced application of fertilizer nutrients have been observed in maize and wheat based systems (Jat et al., 2014a,2014b; Sapkota et al., 2014; Pooniya et al., 2015). The nutrient content of plants, particularly nitrogen, and the LAI also affects the radiation interception efficiency (Dewar, 1996; Scott Green et al., 2003) which in turn affects the conversion efficiency of total incoming solar radiation into dry matter (Fahong et al., 2004). Under field conditions, water stress can modify the plant leaf development and limits its photosynthetic activity and stomatal conductance, hence affecting the whole plant performance, including reduction of crop yield and grain quality (Guimarães, 1996; Fancelli and Dourado Neto, 1991). The incident radiation conversion efficiency (IRCE) also varies with the crop species (Sinclair and Muchow, 1999) under a set of management practices. The water-use efficiency (WUE) is interrelated with IRCE (Sadras and Connor, 1991). These understandings, therefore, lead to support the setting of new benchmarks to evaluate existing agricultural systems and to improve future agricultural systems in order to balance the future need through enhanced yields and the resource use efficiency (Kant et al., 2011; Teixeira et al., 2014).

So, the optimization of both WUE and IRCE of MWMb system is required in north-west part of India for better utilization of the available solar radiation and limited water. Therefore, we conceptualized a research study to investigate and provide new scientific information on the effects of CA-based practices and precision nutrient management in MWMb rotation on crop productivity, water-use and incident radiation conversion efficiency in a sandy loam soil of north-west India. The objective of this research was to assess the productivity, water-use efficiency and incident radiation conversation efficiency of MWMb cropping system under 3 tillage practices and 4 nutrient management strategies.

2. Materials and methods

2.1. Experimental site

The experiment under MWMb rotation was conducted for three consecutive years during 2012–2015 at the research farm of ICAR-Indian Institute of Maize Research, New Delhi, India (28°38′N, 77°11′E and 228.6 m above mean sea level). Maize was sown during the *rainy* season (July-October), wheat in winter (November-April) and mungbean in summer (April–June) season. The site has a semi-arid climate, typically characterized by hot and dry summer and cold winter with a mean annual precipitation of about 652 mm. The soil of the experimental site is a sandy loam in texture (Typic Haplustept) of Gangetic alluvial origin, and well drained with 64.1% sand, 16.9% silt and 19.0% clay, pH 7.9, bulk density 1.63 Mg m^{-3}, hydraulic conductivity (saturated) 0.835 cm h^{-1}, organic carbon 4.89 g kg^{-1} soil, EC 0.32 dS m^{-1}. The moisture content at saturation was 0.38 m^3 m^{-3} and at 0.033 MPa (Field capacity) varied from 22 to 27% and at 1.5 MPa (Permanent wilting point) varied from 8 to 12% in different soil layers of 0–30 cm depth.

2.2. Experiment treatments and design

The experiment was laid out in a split-plot design with tillage/crop establishment practices [Zero tillage with residue retention (ZT), Permanent bed with residue retention (PB), and Conventional tillage with residue incorporation (CT)] as main-plot and nutrient management [Control (unfertilized), Farmers' Fertilizer Practice (FFP), Recommended dose of fertilizers (Ad-hoc), and Nutrient Expert® decision support tool-based fertilizer application (Pampolino et al., 2012) (SSNM)] as sub-plot treatments. The 12 treatment combinations with a harvested subplot size of 30.15 m^2 (7.5 m length x 4.02 m width) were replicated thrice every year (for all the three years) of study. The details of treatment are summarized in Table 1.