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Crop performance in permanent raised bed rice–wheat cropping system in Punjab, India

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ABSTRACT

Raised beds are widely used in agriculture in developed countries and have proven to be an excellent option for wheat. Permanent raised beds may also offer benefits for rice–wheat (RW) systems in South Asia, in terms of both production and the possibility that furrow-irrigation may be more efficient than flood irrigation. The performance of a RW system on permanent raised beds (37 cm wide, 15 cm high, furrow width 30 cm) was compared with conventional cultivation on the flat on sandy loam and loam soils in replicated experiments in central Punjab, India. The experiments commenced with wheat sown in November 2002, and were continued for 8 crops.

Yields of conventionally tilled wheat (CTW) ranged from 3.6 to 4.9 t ha^{-1} and tended to be higher on the loam than on the sandy loam. Yields of wheat on fresh and permanent beds (WB and DDWB, respectively) were similar to yields on CTW and direct-drilled wheat on the flat (DDW) except when establishment was sub-optimal on the beds on both soils in 2004–2005. It was also lower on the beds on the sandy loam in 2002–2003 when tillering did not compensate for the lower sowing rate on the beds. In each case, the poorer performance on beds appeared to be associated with the more rapid drying of the beds than the flats, and thus the need for greater precision in irrigation and sowing management with beds on sandy loam and loam soils. Yield on beds relative to flats did not change as the beds aged.

Yields of transplanted rice on permanent beds (TRB) were depressed relative to yields of puddled transplanted rice (PTR) with the same alternate wetting and drying water management, regardless of age of the bed (from 1st to 8th crop) and soil type. Yields of TRB relative to PTR declined as the beds aged, over the first 2–3 years, from about 80 to 90% to less than 50% of PTR. Biomass production in TRB was always significantly less than in PTR, starting from 35 d after transplanting. Performance of direct-seeded rice on beds (DSRB) was even poorer. Serious root knot nematode infestation was also a serious problem in transplanted rice on the sandy loam in the absence of continuous flooding, on both TRB and PTR. The DSRB suffered from severe iron deficiency each year on both soils despite several iron sprays beginning as early as 15 days after transplanting, and yields declined from about 60% of PTR with the same irrigation scheduling in the first rice crop to less than 25% of PTR in the third rice crop.

Total annual system productivity was highest using puddled transplanted rice (PTR) in rotation with fresh beds (WB) for wheat, CTW or DDW on the flat. Average productivity of these systems over the first 4 years was 9.5 t ha^{-1} y^{-1} on a sandy loam soil and 10.3 t ha^{-1} y^{-1} on a loam soil. Productivity of RW on permanent raised beds with transplanted rice declined as the beds aged, and averaged 77–79% of the productivity of the best systems mainly due to declining yield of TRB relative to PTR. Averaged over the first 3 years, productivity of permanent beds with direct-seeded rice (DSRB) was even lower (only 62–68% of the best systems) due to much lower yields of DSRB.

Permanent bed RW systems seem to have limited potential under the prevailing soil and climatic conditions of Punjab, India, with current varieties and management. Further research on permanent

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raised beds for RW systems should focus on the selection of suitable rice and wheat cultivars, soil health issues such as nematodes and iron deficiency, weed control, irrigation scheduling, N management and soil compaction.

1. Introduction

Rice–wheat (RW) cropping systems are of great importance for food security in South Asia, and are fundamental to employment, income and livelihoods for hundreds of millions of rural poor (Paroda et al., 1994; Yadav et al., 1998; Timsina and Connor, 2001; Gupta et al., 2002). Rice and wheat are grown in sequence annually on about 10 Mha in the Indo-Gangetic Plains (IGP) of India with another 3.5 Mha in Pakistan, Bangladesh and Nepal. The area and productivity of RW systems increased dramatically between the 1960s and 1980s due to the introduction of improved varieties, increased use of fertilisers and pesticides, and expansion of irrigation, much of it via new tubewells. However, since the early 1990s, yields have stagnated or declined, partial factor productivity has decreased, and there are large gaps between potential and farmer yields (Ladha et al., 2003). Therefore, the sustainability of RW systems of the IGP and their ability to increase production in pace with population growth are serious concerns, especially given the evidence of degradation of the resource base for RW systems over the past 30 years. These forms of degradation include declining soil fertility and organic matter content (Yadav et al., 1998; Byerlee et al., 2003), herbicide resistance (Malik et al., 1998), increasing pest problems (Pingali and Gerpacio, 1997), micronutrient deficiencies (Nayyar et al., 2001) and rapidly declining groundwater levels (Pingali and Shah, 1999; Singh, 2000; Hira and Khera, 2000).

RW systems in north-west India are relatively mechanised (35 h.p. tractor-powered tillage and sowing, and combine harvesting) and are practised on a wide range of soils from loamy sands (“non-traditional rice soils”) to clays. Traditional rice cultivation involves puddling (intensive cultivation of saturated soil) followed by hand transplanting and frequent irrigation to maintain continuous ponding until shortly before the harvest. Establishment of wheat after rice typically involves rice straw burning followed by around 6 machinery passes to cultivate and level the fields (Gajri et al., 2002). Puddling offers significant advantages to rice by reducing percolation of water and nutrients, ease of transplanting, better weed control, and lower soil redox potential, which increases the availability of P, Fe and Mn (Ponnamperuma, 1972). However, puddling and continuous flooding for rice can impair soil structure for wheat, including the development of a hard pan which restricts root penetration (Sur et al., 1981; Boparai et al., 1992; Aggarwal et al., 1995; Kirchhof et al., 2000; Kukal and Aggarwal, 2003a) and reduces wheat grain yield (Kukal and Aggarwal, 2003b). Prolonged flooding during the rice phase also reduces the availability of P for subsequent upland crops. Puddling and transplanting for rice also have high water and labour requirements.

New production technologies are needed that increase yield and partial factor productivity of rice and wheat and reduce water use. Many studies in north-west India have shown that continuous ponding is not necessary to maintain rice yields at reasonable levels while providing substantial irrigation water savings (20–40%) (see reviews by Humphreys et al., 2005, 2007). Rice can withstand soil water tensions up to 10–15 kPa, which may occur 2–4 d after the disappearance of ponded water from the field, without a significant reduction in rice grain yield (Sharma, 1989; Hira et al., 2002; Kukal et al., 2005b). This characteristic offers an opportunity to cultivate rice as an upland crop in non-puddled soil with proper irrigation scheduling. Studies in the north-west IGP have shown that rice can be successfully dry seeded or transplanted into non-puddled soils, with or without prior cultivation, followed by intermittent irrigation, with reports of substantial irrigation water savings (Gupta et al., 2002; Hobbs et al., 2002; Qureshi et al., 2004; Malik and Yadav, 2008). Dry seeding of rice in Australia, with or without cultivation, is extremely successful (Beecher et al., 2006). Studies (Lal et al., 1989; Lawrence et al., 1994; Govaerts et al., 2005) in many parts of the world have also shown that tillage is not necessary for wheat. Direct drilling of wheat into rice fields following partial or complete burning, is being adopted rapidly in the north-west IGP (Hobbs and Gupta, 2000; Malik et al., 2004; Singh and Ladha, 2004), with reported irrigation water savings of 20–30% (Humphreys et al., 2005, 2007). Direct drilling reduces tillage costs and also allows timely establishment and therefore higher yields when rice is harvested late relative to the optimum time for land preparation for wheat, or where preparation for wheat is delayed due to wet soil conditions after rice harvest.

Raised beds were introduced to RW systems of the IGP in the mid 1990s, initially for wheat, inspired by the success of irrigated maize–wheat on permanent raised beds in Mexico (Sayre and Hobbs, 2004). Since then, many advantages of growing wheat on beds in the IGP have been reported, including reduced lodging, opportunities for mechanical weeding and relay intercropping, irrigation water savings of about 30%, reduced waterlogging, reduced seed rate of about 30% and opportunities for improved fertiliser placement (Hobbs et al., 2000; OFWM, 2002; Talukdar et al., 2002; Sayre and Hobbs, 2004; Hobbs and Gupta, 2003; Gupta et al., 2003a; Ram et al., 2005). However, the beds are usually destroyed after wheat harvest prior to puddling for transplanting rice; therefore it is not surprising that adoption of beds for wheat in RW systems has been very low to date.

Permanent raised bed RW systems offer the potential additional advantages of reduced or zero tillage for both crops, with large savings in diesel, labour and machinery costs. Other potential benefits include improved soil structure for wheat through controlled traffic and minimum tillage. Improved soil structure in permanent beds may, however, result in increased deep drainage and leaching losses from rice compared with PTR. In their reviews, Humphreys et al. (2005, 2007) reported irrigation water savings of 12–60% for direct-seeded and transplanted rice on beds in the IGP, but with variable effects on yield and water productivity. There is, however, little detailed information available on the performance of permanent bed RW systems. Therefore we established field experiments with the objective of comparing the performance of RW systems on permanent raised beds with performance using conventional practice (puddled transplanted rice grown in rotation with wheat sown on the flat after conventional tillage or by direct drilling into undisturbed soil). Performance criteria included crop growth and yield (this paper), changes in soil physical properties (Kukal et al., 2008), water dynamics and components of the water balance (Humphreys et al., 2008), and crop water productivity (forthcoming). Detailed measurements of a range of crop, soil and water parameters were