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Factors affecting irrigation water savings in raised beds in rice and wheat

S.S. Kukal[a,*], Sudhir-Yadav[a,b], E. Humphreys[c], Amanpreet-Kaur[a], Yadvinder-Singh[a], S. Thaman[a], B. Singh[d], J. Timsina[c]

[a] Department of Soils, Punjab Agricultural University, Ludhiana-141004, India
[b] University of Adelaide, Adelaide, Australia
[c] International Rice Research Institute, Los Baños, Philippines
[d] Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia

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ABSTRACT

Raised beds have been proposed for rice–wheat (RW) cropping systems in the Indo-Gangetic Plains as a means of increasing irrigation water productivity, among many other potential benefits. Field experiments were carried out in Punjab, India, during 2002–2006 to compare irrigation water use and productivity of transplanted rice and drill-sown wheat on fresh and permanent beds and conventionally tilled flats.

Total irrigation applications to conventionally tilled wheat (CTW) and wheat on beds were similar on both soils, in both small plots and in a farmers' field, with one exception—irrigation amount on fresh beds was 10% lower than on permanent beds in the farmers' field. Yields on beds and CTW were similar on the loam, but were sometimes lower on beds on the sandy loam. In the small plots, irrigation water productivity (WP_{IW}) on beds and in CTW was similar (mean 2 g kg^{-1}) on the loam, but about 20% on the sandy loam, mainly due to lower yields. In the farmers' field, WP_{IW} (1.5 g kg^{-1}) was 15% higher on the fresh beds than on the permanent beds due to lower irrigation amount.

The amount of irrigation water applied to rice on permanent beds and puddled transplanted rice (PTR) was similar in the small plots on the sandy loam. However, on the loam, irrigation application to the permanent beds was significantly higher, by about 18%. There was a significant decline in grain yield on the permanent beds relative to that in PTR over the 4 years, on both soils. WP_{IW} on the permanent beds decreased with time on both soils, mainly due to declining grain yield.

Irrigation applications to rice on fresh beds were lower than applications to the puddled flats (by 11% on the sandy loam, and by 20–24% on the loam) while yields were 7 and 15% lower, resulting in similar WP_{IW} on fresh beds and PTR. Reducing irrigation application from full-furrow to half-furrow depth in the farmers' field reduced the irrigation amount on both permanent and fresh beds by 40–50%, but yield was also reduced by about 20%.

The results show that beds do not always save irrigation water or increase WP_{IW} in comparison with conventionally tilled flat fields, for both rice and wheat under our soil and environmental conditions. The effects of the beds depend on irrigation/water management (of both beds and flats), age of the beds and soil type. The effect of beds on irrigation amount is also likely to depend on factors such as depth to the water table, levelness of the soil surface, and size and shape of fields relative to irrigation flow rate.

1. Introduction

A range of resource conserving technologies (RCTs) is being promoted for rice–wheat (RW) systems in the Indo-Gangetic Plains of South Asia (RWC-CIMMYT, 2003; Gupta and Seth, 2006) to increase resource use efficiency, profitability, productivity and sustainability of these systems, while reducing their adverse environmental impacts. The objective of increasing water productivity (g grain kg^{-1} water depleted) tops the list in north west India because of rapidly declining water tables (Hira et al., 2005), and the fact that the productivity of RW systems in this region is critical for national food security. One such RCT is the raised bed system (Connor et al., 2003; Sayre and Hobbs, 2004; Humphreys et al., 2008a).

In most situations in the IGP, wheat grows successfully on raised beds, with similar or higher yields and about 30% less irrigation water than conventional tillage on the flat (Meisner et al., 2005; Ram et al., 2005; Jat et al., 2008; Lauren et al., 2008). Most experiments comparing wheat on beds and flats schedule irrigations on the same day for both treatments, and deliberately apply a reduced

* Corresponding author. Tel.: +91 161 2401960; fax: +91 161 2400945.
E-mail address: sskukal@rediffmail.com (S.S. Kukal).

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Table 1
Soil properties of the experimental sites.

Depth (cm)	Bulk density[a] ($Mg\ m^{-3}$)	Clay (%)	Sand (%)	SWC at field capacity[b] ($cm^3\ cm^{-3}$)	SWC at 1500 kPa ($cm^3\ cm^{-3}$)	pH (1:2)	K_{unsat}[c] (1 kPa) ($mm\ h^{-1}$)	K_{unsat}[c] (7 kPa) ($mm\ h^{-1}$)
Sandy loam								
5–10	1.61	17.2	65.6	0.26	0.07	6.7	12 (15 cm)	10 (15 cm)
20–25	1.76	15.3	67.3	0.27	0.07	7.3	25 (25 cm)	14 (25 cm)
40–45	1.61	16.6	71.4	0.23	0.06	7.6	166 (45 cm)	76 (45 cm)
70–75	1.53	14.8	72.2	0.21	0.06	7.7		
100–105	1.53	14.0	73.8	0.21	0.07	7.8	183 (105 cm)	171 (105 cm)
130–135	1.52	8.2	80.9	0.21	0.05	ND[d]		
160–165	1.52	8.6	88.1	0.20	0.05	ND[d]	362 (165 cm)	306 (165 cm)
Loam								
5–10	1.55	17.4	40.0	0.33	0.09	8.3	9 (15 cm)	6 (15 cm)
20–25	1.79	23.2	28.1	0.34	0.09	8.3	3 (25 cm)	1 (25 cm)
40–45	1.70	25.0	31.0	0.34	0.10	8.3	11 (45 cm)	2 (45 cm)
70–75	1.71	26.0	25.8	0.34	0.13	8.2		
100–105	1.67	29.9	22.6	0.34	0.14	8.2	14 (105 cm)	3 (105 cm)
130–135	1.67	30.8	20.8	0.34	0.14	ND[d]		
160–165	1.67	29.3	21.2	0.34	0.14	ND[d]	8 (165 cm)	2 (165 cm)

[a] Figures in parentheses are the exact depth of determination.
[b] Determined in the field; SWC is volumetric soil water content.
[c] K_{unsat} is unsaturated hydraulic conductivity determined in the field using disc permeameters at tensions of 1 and 7 kPa.
[d] Not determined.

volume to the beds (e.g. 70% of that applied to the flats). Few studies have determined whether the performance of conventionally tilled wheat on flats can be maintained with a similar (reduced) irrigation application.

Many researchers and farmers have also shown that it is possible to grow transplanted rice on beds in the IGP, but with variable performance in comparison with PTR in terms of yield and irrigation water amount (Humphreys et al., 2008a). Irrigation water savings in rice on raised beds in comparison with PTR ranged from 9 to 58% (Sharma et al., 2002; Balasubramanian et al., 2003; Singh et al., 2005; Jehangir et al., 2007; Choudhury et al., 2007; Bhushan et al., 2007), with the largest savings associated with comparisons of intermittently irrigated beds and continuously flooded PTR (Choudhury et al., 2007; Humphreys et al., 2008b,c). Unfortunately, many comparisons of rice on beds and flats, especially those in farmers' fields, do not report the water management of the PTR, and few studies have systematically compared rice on beds and PTR with similar alternate wetting and drying (AWD) irrigation management. It is well-established that use of AWD with PTR gives large irrigation water savings of 15–40% on the permeable soils and the deep watertable conditions of north west India, with little effect on yield (Sandhu et al., 1980; Sharma, 1989, 1999; Choudhary, 1997; Hira et al., 2002; Humphreys et al., 2005, 2008c; Kukal and Aggarwal, 2002; Kukal et al., 2005a,b, 2008). It is unclear whether the water savings on intermittently irrigated beds would be similar to the savings with intermittent ponding of PTR, or whether the beds confer further advantages in terms of water savings. Alternatively, the absence of puddling with beds could result in higher irrigation amounts. Furthermore, does it make any difference if the beds are fresh or permanent, given the possible development of macroporosity in permanent beds, and thus the possibility of bypass flow increasing irrigation amount?

The work reported here aimed to compare irrigation water use and irrigation water productivity (WP_I) of rice and wheat on fresh and permanent raised beds and conventionally tilled flats on coarse and medium textured soils overlying deep water tables in Punjab, India.

2. Materials and methods

Replicated small plot (2002–2006) and un-replicated farmer field-scale (2004–2006) experiments were conducted at two locations with different soil types (Table 1) in Punjab, India. The experiments compared a range of layout/establishment treatments for each crop. Details of the site, experimental design, management, weather, crop performance and water monitoring are provided in Yadvinder-Singh et al. (2009) and Humphreys et al. (2008b), and only those details essential to the focus of this paper are presented here. This paper compares irrigation water use and water productivity for three treatments: (1) conventionally tilled wheat on the flat (CTW) grown in rotation with puddled transplanted rice (PTR), (2) permanent raised beds with transplanted rice (TRBperm) followed by drill-sown wheat (WBperm), and (3) fresh beds (soil cultivated) and new beds formed prior to transplanting rice (TRBfresh) or sowing wheat (WBfresh).

2.1. Experimental sites

The region has a sub-tropical climate, with hot, wet summers and cool, dry winters. Average annual rainfall is 734 mm, 44% of annual pan evaporation. One experimental site was on a sandy loam on the Punjab Agricultural University (PAU) farm at Ludhiana (30°56′N, 75°52′E; 247 m ASL), and the second site was on a loam in a farmer's field near Phillaur (31°03′N, 75°46′E; 245 m ASL), about 15 km from PAU. Both sites had been under a continuous RW cropping system for at least 20 years. The depth to the groundwater at each site was over 10 m, and groundwater salinity was 0.8–0.9 $dS\ m^{-1}$.

2.2. Replicated small plot experiments

Crop management for both wheat and rice followed PAU recommended practices and is described in Yadvinder-Singh et al. (2009). Plot size was 10.7 m × 12 m on the loam and 6.7 m × 12 m on the sandy loam, with earth bunds around each plot.

2.2.1. Wheat

The rice was harvested at ground level in October each year, and all straws were removed. All plots were pre-irrigated after 3–5 weeks of bare fallow after which the CTW plots were cultivated. In the first year (November 2002), all the raised beds for wheat were fresh whereas in subsequent years, a treatment of fresh raised beds (in rotation with PTR) was also maintained along with the permanent beds. The width of the beds (mid-furrow to mid-furrow) was