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

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\section*{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\textsubscript{w}) on beds and in CTW was similar (mean 2 g kg\textsuperscript{-1}) on the loam, but about 20% on the sandy loam, mainly due to lower yields. In the farmers’ field, WP\textsubscript{w} (1.5 g kg\textsuperscript{-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\textsubscript{w} 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\textsubscript{w} 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\textsubscript{w} in comparison with conventionally tilled flat fields, for both rice and wheat under our soil and environmental conditions. 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.

\section*{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\textsuperscript{-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 (Meisinger 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

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field-scale (2004–2006) experiments were conducted at two loca-

2. Materials and methods

India. and medium textured soils overlying deep water tables in Punjab, and permanent raised beds and conventionally tilled flats on coarse

...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...presence 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 (WPI) of rice and wheat on fresh and permanent raised beds on the Punjab Agricultural University (PAU) farm at Ludhiana (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

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.

Table 1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Bulk densitya (Mg m⁻³)</th>
<th>Clay (%)</th>
<th>Sand (%)</th>
<th>SWC at field capacityb (cm³ cm⁻³)</th>
<th>SWC at 1500 kPa (cm³ cm⁻³)</th>
<th>pH (1:2)</th>
<th>Kunsatc (1 kPa) (mm h⁻¹)</th>
<th>Kunsata (7 kPa) (mm h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td></td>
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<td></td>
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<tr>
<td>5–10</td>
<td>1.61</td>
<td>17.2</td>
<td>65.6</td>
<td>0.26</td>
<td>0.07</td>
<td>6.7</td>
<td>12 (15 cm)</td>
<td>10 (15 cm)</td>
</tr>
<tr>
<td>20–25</td>
<td>1.76</td>
<td>15.3</td>
<td>67.3</td>
<td>0.27</td>
<td>0.07</td>
<td>7.3</td>
<td>25 (25 cm)</td>
<td>14 (25 cm)</td>
</tr>
<tr>
<td>40–45</td>
<td>1.61</td>
<td>16.6</td>
<td>71.4</td>
<td>0.23</td>
<td>0.06</td>
<td>7.6</td>
<td>166 (45 cm)</td>
<td>76 (45 cm)</td>
</tr>
<tr>
<td>70–75</td>
<td>1.53</td>
<td>14.8</td>
<td>72.2</td>
<td>0.21</td>
<td>0.06</td>
<td>7.7</td>
<td>183 (105 cm)</td>
<td>171 (105 cm)</td>
</tr>
<tr>
<td>100–105</td>
<td>1.53</td>
<td>14.0</td>
<td>73.8</td>
<td>0.21</td>
<td>0.07</td>
<td>7.8</td>
<td>183 (105 cm)</td>
<td>171 (105 cm)</td>
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<tr>
<td>130–135</td>
<td>1.52</td>
<td>8.2</td>
<td>80.9</td>
<td>0.21</td>
<td>0.05</td>
<td>NDa</td>
<td>8.2</td>
<td>14 (105 cm)</td>
</tr>
<tr>
<td>160–165</td>
<td>1.52</td>
<td>8.6</td>
<td>88.1</td>
<td>0.20</td>
<td>0.05</td>
<td>NDa</td>
<td>8.2</td>
<td>14 (105 cm)</td>
</tr>
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</table>

| 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   | 14 (105 cm)           | 3 (105 cm)            |
| 100–105   | 1.67                   | 29.9    | 22.6    | 0.34                            | 0.14                      | NDa   | 8.2                   | 14 (105 cm)           |
| 130–135   | 1.67                   | 30.8    | 20.8    | 0.34                            | 0.14                      | NDa   | 8.2                   | 14 (105 cm)           |
| 160–165   | 1.67                   | 29.3    | 21.2    | 0.34                            | 0.14                      | NDa   | 8.2                   | 14 (105 cm)           |

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

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 drift-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.

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2.2.1. Wheat

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67 cm, with 37 cm wide flat tops, and 15 cm furrow depth. Wheat (PBW343) was drill sown in early to mid November each year and harvested in early to mid April in the following year, leaving the fields bare fallow for about 8 weeks prior to pre-irrigation for rice. Row spacing was 20 cm on the flats, and 2 rows with 20 cm spacing were planted on the top of each bed. Weeds were well-controlled on both beds and flats by spraying sulfosulfuron (32.5 g ha\(^{-1}\) a.i.) within a week after the first post-sowing irrigation.

2.2.2. Rice

The plots were pre-irrigated for rice in early June each year, and the furrows were cleaned and the beds reshaped using a tractor-mounted bed planter. Thus for rice the raised beds were maintained as permanent beds right from the first crop, except during 2006 when fresh beds were introduced in one treatment. For PTR, several cultivations were carried out prior to puddling. Transplanting of the puddled plots and beds took place at the same time. A short duration variety (PR115) was grown in the first 2 years, followed by the longer duration PR118 in 2005 and 2006. Weeds were well-controlled in PTR using butachlor 50 EC (1.31 ha\(^{-1}\)) 6–7 d after transplanting. Weeds were controlled on the beds using soft (pretihlor + safner (1.251 ha\(^{-1}\); a.i. 37.5EC)) and several hand weedings.

2.3. Farmers' field-scale experiments

Fresh and permanent raised beds were compared with conventional tillage in large, un-replicated blocks running the full length (~60 m) of a farmer's field during 2005–2006 on the loam at Phillaur. The size of the blocks ranged from about 600 to 1200 m\(^2\), within the range normally used for the irrigation of wheat, but a little smaller than the typical size for rice (~2000 m\(^2\)). The dimensions of the beds were the same as in the small plots. Both rice and wheat were raised as in the small plots, except for a range of additional irrigation treatments described below.

2.4. Irrigation

All small plots and large blocks were irrigated, one at a time, with groundwater via a piped irrigation system. Irrigation volume was measured with a Woltman\textsuperscript{®} helical turbine meter. The same meter was used for all the small plots and the adjacent large blocks in the farmers' field. Total irrigation reported for each crop includes pre-tillage and pre-sowing irrigations were applied. In the replicated small plots, at each irrigation, the same amount of irrigation water was applied to all four replicates within each treatment.

2.4.1. Small replicated plots

Prior to wheat sowing, all plots received a pre-sowing irrigation, followed by a common irrigation around the time of crown root initiation (CRI), 3–4 weeks after sowing. The amount of water applied at CRI was the amount required to fully flood the flat plots, or to fill the furrows on the bed plots without overtopping the beds. Subsequent irrigation scheduling for both flats and beds was based on net cumulative pan evaporation (CPE-rain), using \(\frac{\text{IW}}{\text{CPE-rain}}\) = 0.9–1.0 (Prihar et al., 1976), where IW is the amount of irrigation water applied at the preceding irrigation. The same amount of irrigation water was applied to fresh and permanent raised beds in the wheat.

All rice treatments were irrigated prior to cultivation and puddling or prior to reshaping the beds, and then irrigated daily for the first 2 weeks after transplanting (except when there was significant rain). Thereafter, irrigations were applied 2 d after the floodwater had disappeared from the flat plots and furrows (–2 d). In the absence of rain, the soil surface in the puddled plots remained ponded for 10–15 h, while the furrows only remained ponded for about 2–3 h. Thus the day after irrigation, the floodwater had already disappeared from both treatments, and irrigations usually occurred on the same day in both puddled and bed plots. Irrigation water was added to the flat plots until the floodwater was 50–80 mm deep. The furrows in transplanted rice on beds were filled close to the top of the beds at each irrigation.

2.4.2. Farmer field blocks

In 2005/2006, CTW and wheat on fresh and permanent beds (5th crop) were compared in 60 m long blocks, with irrigations scheduled when \(\frac{\text{IW}}{\text{CPE-rain}}\) = 0.9 in CTW, but more frequently on the beds (ratio of 1.2).

The irrigation treatments compared during rice in the farmer field blocks in 2005 and 2006 were: (i) irrigation with a full-furrow depth of water 2 d after the floodwater had dissipated from the furrows (Full-2 d), (ii) irrigation with a half-furrow depth of water (Half-2 d), and (iii) irrigation with a half-furrow depth when soil tension at 20 cm depth in the beds increased to 16 kPa (Half-SMP). These treatments were compared on permanent beds in both 2005 and 2006. In 2006, the same irrigation treatments were also compared on fresh beds, and there was also a PTR treatment irrigated 2 d after complete disappearance of ponded water from the field (PTR-2 d), but with daily irrigation for the first fortnight after transplanting as for the transplanted rice on beds.

2.5. Statistical analysis

Analysis of variance was used to compare treatment yields within each year in the experiments. Regression analysis of normalized yield (yield on the beds relative to yield with conventional tillage) over time (year) was used to identify whether aging of the beds affected yield on the beds. Normalized yield was used to remove the effect of seasonal conditions on crop performance, and the highest yielding replicate of PTR each year was used as the reference (as an estimate of potential yield). A paired t-test was used to determine whether the slope of the regression for normalized yield of the beds was significantly different from the slope of the regression for normalized yield of PTR. Similar analyses were performed for normalized irrigation water use and normalized WP\textsubscript{e}. Regression analysis was also used to investigate relationships between irrigation water amount and net evaporative demand (Epan-rain). As there was no significant regression relationship for either crop, on beds or flats, analysis of variance was used to compare irrigation water use of the treatments, with years as replicates. In the non-replicated farmers' fields, standard deviation of grain yield was calculated from 3 samples (21–48 m\(^2\) each) per treatment.

3. Results

Rainfall during the wheat season at both sites was lower than the long-term average at PAU (201 mm) in three of the four seasons, and ranged from a low of around 50 mm on both sites in 2005/2006 to around 200 mm in 2002/2003 (Yadvinder-Singh et al., 2009). In the rice season, rainfall was close to the long-term average (580 mm) in two years, but was below this (220–410 mm) in 2004 and 2006.

3.1. Wheat

3.1.1. Small replicated plots

Total irrigation amounts on both soils were similar in respective years, and ranged from about 100 to 300 mm over the 4 years (Fig. 1a and d). Analysis of variance over the 4 years showed no significant difference in irrigation amounts between the three treatments (CTW, fresh beds, and permanent beds). Yields on the beds tended to be lower than in CTW on the sandy loam, with some
significant differences, but there was no trend on the loam (Fig. 1b and e). There was no significant difference in the slope of the relationships of normalized yield of the beds and CTW with time, nor for normalized WP$_{IW}$ and time, on either soil. Over the 4 years, average WP$_{IW}$ was similar in CTW on both soils and on the beds on the loam (2.0–2.1 g kg$^{-1}$), but was about 20% lower on the beds on the sandy loam, mainly due to lower yields (Fig. 1c and f). WP$_{IW}$ was unusually high in CTW on both soils in 2004–2005 due to the low irrigation amount in that treatment. In that year, there was significant rain in January just before irrigation of CTW was due, whereas the beds had already been irrigated. Following that there were timely falls of rain in February and March, and no further irrigations were applied. Trends in input water productivity (amount of grain per unit of irrigation plus rain) were similar to trends in WP$_{IW}$ (data not presented).

3.1.2. Farmer field blocks

In the farmer field blocks on the loam in 2005–2006, irrigation amounts in CTW and permanent beds were similar, but 14% higher than in the fresh beds (Fig. 2a). Yields of all three treatments in the farmer blocks were similar in respective years, except for lower yield on the permanent beds than in CTW in 2004–2005 (Fig. 2b). WP$_{IW}$ in fresh beds (1.5 g kg$^{-1}$) was 11 and 16% higher than in CTW and permanent beds, respectively, in 2005–2006 (Fig. 2c).

3.2. Rice

3.2.1. Small replicated plots

In the small plots on the sandy loam, there were no consistent trends in irrigation water use of PTR (mean 2370 mm) compared with permanent beds (mean 2310 mm) across the years (Fig. 3a). However on the loam, irrigation applications to the permanent beds were consistently higher than in the puddled plots, by 16–21% (Fig. 3d). Analysis of variance over the 4 years showed that irrigation water application to the permanent beds was significantly higher than to PTR on the loam, but not on the sandy loam (Fig. 4a and b). In 2006 when fresh beds were introduced for rice, irrigation applications to the fresh beds tended to be lower than to the permanent beds and PTR (by 11 and 24%), on the sandy loam and loam, respectively.

Yields of rice on permanent beds were always significantly lower than yields of PTR on the same soil, and declined to 33–44% of the yield of PTR as the beds aged (Fig. 3b and e). The slope of the regression of normalized yield for the permanent beds against time (year) was significantly different ($p < 0.05$) from that of normalized PTR on both soils (sandy loam $R^2 = 0.69$, loam $R^2 = 0.81$). However, when fresh beds were introduced in 2006, yield of rice on fresh beds was within 7–15% of yield of PTR, with no significant difference on the sandy loam. Irrigation water productivity in...
PTR ranged from 0.21 to 0.39 g kg\(^{-1}\) and there was a trend for consistently higher \(WPI_W\) on the loam (mean 0.29 g kg\(^{-1}\)) than on the sandy loam (mean 0.23 g kg\(^{-1}\)) (Fig. 3c and f). As for yield, there was a trend for normalized \(WPI_W\) of rice on permanent beds to decline as the beds aged, from 0.74–0.75 in 1-year-old beds on both soils to 0.49 in 4-year-old beds on the sandy loam, and to 0.28 on the loam. The regression of normalized \(WPI\) against time on the loam was significant \((R^2 = 0.81, p < 0.05)\). However, \(WPI_W\) on the fresh beds was similar that of PTR due to similar reductions in both yield and irrigation amount on the fresh beds. Trends in input water productivity were similar to trends in \(WPI_W\), with mean values in PTR of 0.19 and 0.23 g kg\(^{-1}\) on the sandy loam and loam, respectively.

#### 3.2.2. Farmers’ scale field plots

As in the small plots, irrigation amount was higher in the permanent beds than fresh beds irrigated with a full-furrow, and the amount in the fresh beds was lower than in PTR (Fig. 5a). Irrigation water use in the permanent beds irrigated with a full-furrow was similar to that in PTR. Decreasing water depth in the furrows to half, with the same 2-d scheduling, decreased irrigation water use in both the permanent and the fresh beds to about two-thirds of that in PTR. SMP-based scheduling with the furrows half-filled further reduced irrigation amount in both years. Interestingly, cumulative irrigation during the first 2 weeks after transplanting (a period of daily irrigation in all treatments, with furrows filled to the top each day) increased faster in the permanent beds than in PTR (data not presented). Once the irrigation scheduling (−2 d) commenced, the rate of increase in cumulative irrigation was higher in PTR than in all bed treatments, with the slowest rate of accumulation in the permanent beds with the furrows only half-filled at each irrigation. A possible explanation is bypass flow in the macropores in the permanent beds until the soil swelled and the cracks closed.

Yield of rice on the permanent beds in the large blocks was reduced greatly (by 40–60% depending on irrigation management) compared with yield of PTR, while yield on fresh beds with a full-furrow was similar to yield in PTR (Fig. 5b). Yield declined by 20–25% when furrow depth at each irrigation was reduced to half.

Irrigation water productivity of the permanent beds was always much lower than that of \(WPI_W\) (0.54 g kg\(^{-1}\)) (Fig. 5c), regardless of irrigation management of the beds, mainly due to lower yield. Irrigation water productivity of the fresh beds (0.39–0.54 g kg\(^{-1}\)) was roughly double that of permanent beds in respective irrigation treatments due to higher yield and lower irrigation amount. Half-SMP (0.54 g kg\(^{-1}\)) had the same \(WPI_W\) as PTR.

### 4. Discussion

#### 4.1. Wheat

The similar irrigation amounts for fresh and permanent beds and CTW in the small plots are inconsistent with the findings of many small plot experiments (Meisner et al., 2005; Ram et al., 2005; Jat et al., 2008; Lauren et al., 2008). This is probably because the same irrigation management rule, based on irrigation amount and CPE-rain, was used for all treatments in our experiments. Other studies have systematically applied less irrigation water to the flat and bed plots, through scheduling irrigations on the same day and/or deliberately applying less water to the beds, and without testing the performance of CTW with a similar reduced application.

However, the reality is that in full-sized, conventionally tilled farmers’ fields it may not be practically possible to reduce irrigation amount to the lower amounts that can be applied to the beds because of poor leveling and/or large irrigation block size relative to flow rate, and consequently a larger amount of water is needed to completely cover the block. The use of furrows/beds hastens the speed with which irrigation water reaches the other end of the field and thus reduces irrigation amount, as the furrows occupy less than half the area of the field. The reported irrigation water savings for wheat on beds are generally larger in farmers’ fields viz. 45–54% in Haryana (Singh et al., 2002), 34% in Pakistan (Kahlown et al., 2006) than in small plot studies (0–33%) (Sharma et al., 2002;
Fig. 3. a–f Effect of layout on irrigation amount, grain yield and irrigation water productivity for rice in small replicated plots. All treatments irrigated 2 d after disappearance of floodwater from soil surface (flat plots, furrows). Vertical bars are LSD ($p = 0.05$) for comparison of treatments within year. Note: within each treatment, the same amounts of irrigation were applied to all replicates, hence the lack of error bars for irrigation and irrigation water productivity. PTR = puddled transplanted rice; TRBperm = transplanted rice on permanent beds; TRBFresh = transplanted rice on fresh beds.

Aggarwal and Goswami, 2003; Choudhury et al., 2007; Bhushan et al., 2007; Jat et al., 2008; Lauren et al., 2008), although Jehangir et al. (2007) found lower average irrigation water savings (14–20%) on beds in 9 farmers’ fields in Pakistan. Although it was not reported, the above farmer field studies are likely to have been on fresh beds, while the small plot studies involved permanent beds. Using the same irrigation scheduling rules in fresh and permanent beds in the farmer field blocks on the loam, we found 10% lower irrigation application on fresh beds than permanent beds. Our visual observations indicated greater cracking and more biopores (rat holes, worm holes) on the permanent beds on the loam (but not on the sandy loam), which could result in higher irrigation amounts on permanent beds.

Unfortunately, very few reports of comparisons in farmers’ fields provide information on leveling, layout, block size and flow rate, despite the fact that these factors are important determinants of

Fig. 4. a and b Effect of layout on irrigation amount in rice over 4 seasons on (a) sandy loam and (b) loam soils. Vertical bars are LSD ($p = 0.05$).
irrigation efficiency. The recommended size of an irrigation block for wheat in Punjab, India is small, one-sixth of an acre (approx. 10 m × 60 m), although in practice farmers use slightly larger blocks (typically 0.25 acres, approx. 15 m × 60 m), with a typical irrigation time of 1–2 h. With such small blocks and irrigation times, irrigations are likely to be relatively efficient. On the other hand, wheat irrigation blocks in RW systems in Punjab, Pakistan can be up to several acres on large landholdings. In farmers’ fields in Pakistan, laser leveling and beds/furrows resulted in average wheat irrigation water savings of 21 and 34%, respectively, in comparison with conventionally tilled non-lasered fields (Kahlown et al., 2006).

4.2. Rice

Our findings of similar or higher irrigation applications to rice on beds compared with PTR in small plots and large blocks are also inconsistent with the findings of many other studies (Sharma et al., 2002; Balasubramanian et al., 2003; Singh et al., 2005; Choudhury et al., 2007; Jehangir et al., 2007; Bhushan et al., 2007; Jat et al., 2008; Lauren et al., 2008). As for wheat, greater cracking and bio-porosity on the permanent beds on the loam may have led to bypass flow and hence higher irrigation amounts on permanent beds on this soil. The large effect of water depth in the furrows on irrigation water use in the permanent beds is also consistent with macro-pore flow. On a sodic silt loam, Sharma et al. (2002) found that infiltration rate in the beds was almost double that in PTR.

While reducing the depth of water in the furrows from full to half at each irrigation greatly reduced irrigation amount, this was at the cost of yield, more so as the beds aged, with the net result of lower WP_{IW} on the permanent beds. The use of fresh beds restored yield and WP_{IW} to values similar to PTR.

There are many advantages of permanent beds for farmers, especially labour and tractor diesel savings and thus large cost savings, plus reduced greenhouse gas emissions from burning diesel. However, the effects on irrigation and crop water use (ET) and water productivity with respect to irrigation and ET in farmers’ fields require further quantification for a range of agro-ecological situations. Further studies are needed to rigorously test the hypothesis of lower irrigation requirement on beds in farmers’ fields in comparison with conventional tillage, for both rice and wheat, using the recommended irrigation management for the conventionally tilled treatments as well as current farmer practice.

5. Conclusions

We found that permanent raised beds did not save irrigation water in rice in comparison to puddled flats when irrigated with the same irrigation scheduling rules on sandy loam and loam soils with deep watertables. Irrigation amount was similar for PTR and transplanted rice on permanent beds on a sandy loam, and higher on permanent beds on a cracking loam, when a full-furrow depth of irrigation was applied. However, irrigation amounts on fresh beds were less than in PTR on both soils. In wheat, applying irrigation on the basis of the same IW/(CPE-pan) ratio for both beds and CTW resulted in similar irrigation water applications to beds and flats, on average, but the results varied depending on the incidence of rainfall in relation to timing of irrigations.

More comprehensive experiments are needed in farmers’ fields to rigorously compare irrigation amounts on beds and flats, with irrigations managed using recommended practice as well as farmers’ practice. Further studies are also needed to determine the optimum irrigation scheduling for rice and wheat on beds. Such studies should include determination of all components of the water balance. It is only by doing a complete water balance that conclusions can be drawn about the magnitude and types of water savings on beds in comparisons with flats.

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References


