Water balance in dry seeded and puddled transplanted rice in Punjab, India

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Abstract
Rice systems that increase production using less water are urgently needed, especially in North West India where ground water is over-exploited. Replacing the traditional puddled transplanted rice (PTR) with dry seeded rice (DSR) is often proposed as a means of increasing water productivity and saving water. A field study was conducted in Punjab, India, in 2008 to investigate components of the water balance and water productivity in DSR and PTR with different irrigation schedules. Irrigation scheduling was based on different thresholds of soil water tension (SWT. The input water productivity (WP_{I+R}) of rice was significantly higher in DSR irrigated at 20 kPa (0.71 g/kg) than in all other treatments followed by PTR at 20 kPa (0.50 g/kg), The differences in WP_{I+R} between PTR and DSR at 20 kPa were largely due to reduced seepage. However, deep drainage beyond 0.6 m soil depth was higher in DSR, presumably due to the absence of hard pan in the non-puddled system. There was no significant difference in evapotranspiration (~ 600 mm) between DSR and PTR when irrigation was scheduled on the basis of SWT.

Key Words
Irrigation schedule, Soil matric potential, Evapotranspiration, Water productivity.

Introduction
Over exploitation of ground water resources is a major threat to the sustainability of the traditional system of puddled transplanted rice (PTR) production in Indo-Gangetic Plains. Rodell *et al*. (2009) reported a groundwater depletion rate of 4.0±1.0 cm/yr over the North West Indian states of Rajasthan, Punjab and Haryana. The alarming rate of ground water decline is forcing researchers and farmers to modify their present production system to a water-wise system. The conventional method of rice growing is not only a water-guzzling but also cumbersome and laborious. In Punjab, where agriculture is highly dependent upon migrant labour, labour scarcity, especially for transplanting is another major concern in the existing production system. Unscheduled electricity power cuts due to high demand in both industrial and farming sectors also adversely affect farming practices. Both these factors will increasingly result in delayed transplanting, which may reduce rice yield and delay sowing of wheat.

Studies in the north-west IGP have shown that rice can begrown successfully dry seeded into non-puddled soils, with or without prior cultivation. Dry seeded rice (DSR) provides a gateway for advancing crop establishment to make better use of early season rainfall, and facilitates an increase in crop intensification in rice based systems (Tuong *et al*. 2000). However, DSR needs to be sown earlier, so the field is exposed to higher evaporative demand for a much longer period than a puddled transplanted field. However, Bouman (2001) claimed the potential water savings at the field level in upland rice due to less evaporation since there is no permanent ponded water layer, and the amount of water used for puddling is eliminated altogether. However, many researchers have found similar input water productivity (WP_{I+R}) for both dry seeded and conventional PTR (Cabangon *et al*. 2002; Singh *et al*. 2005; Bhushan *et al*. 2007; Choudhury *et al*. 2007).

The effect of DSR versus PTR on water use and water productivity is not well understood, and will depend on many factors including climate, soil type and crop management (especially irrigation management). There is need to study the water balance components viz. irrigation water inputs, deep drainage, runoff and evapotranspiration (ET), so as to objectively compare the water use and water productivity of DSR with that of PTR. The present study aimed to do this for a range of irrigation schedules.

Materials and methods
Experimental site
The study was carried out at the research farm (30°54′ N, 75°98`E, 247 m ASL) of Punjab Agricultural University, Ludhiana, India during 2008. The soil is clay loam with 0.5% organic carbon content. The climate of the region is sub-tropical with hot, wet summers and cool dry winters.

Treatments
The experiment was laid out in 4 replicates in a split plot design with 2 establishment method (EM - dry-seeding and puddled-transplanting) in main plots and 4 irrigation scheduling (IS - daily, and irrigation when the soil water tension (SWT) at 20 cm increased to 20, 40 or 70 kPa) treatments in sub-plots . The daily irrigated PTR treatment was continuously flooded; however this was not the case in the daily DSR because of the high infiltration rate. The daily treatments were topped up to 50 mm standing water depth. The alternate wetting and drying (AWD) tension-based treatments received 50 mm at each irrigation. Sub-plot size was 9 m x 7 m. The sub-plots were bounded by earthen bunds with a plastic lining to a depth of 0.5 m.

The seedling nursery for transplanting and the DSR plots were sown with the medium duration (144 d) variety 'PAU-201' on 9th June 2008. The DSR was sown with a hand plough at 40 kg seed/ha (establishment density 150-180 plants/m^2) and a row spacing of 20 cm. Transplanting was on 5th July in rows 20 cm apart and plant to plant spacing of 15 cm. For the first 45 d after sowing, the DSR was irrigated to maintain soil water tension at 10-15 kPa at 10 cm soil depth to avoid stress during crop establishment. All PTR treatments were continuously flooded for the first 15 days after transplanting prior to commencement of the irrigation scheduling treatments.

Crop management
Recommended fertilizer and other crop management practices were followed, and control of weeds, pests and diseases was excellent. The crop was harvested at approximately 15-20 % grain moisture content on 21st October (daily irrigated treatments) and 3rd November (other treatments). Grain and straw yield were determined on an area of 5 m x 5 m in the middle of the plots.

Water balance measurements
All components of the water balance were measured directly or indirectly, except for ET which was estimated from the water balance equation:

$$I + R = R_{off} + S + D + \Delta SWC + ET \quad (1)$$

The volume of irrigation (I) water volume applied to each plot was measured with a Woltman® helical turbine meter. Rainfall (R) was measured using an automatic rain gauge installed in the centre of the experimental site. Runoff (R_{off}) occurred on heavy rainfall days and was calculated from the amount of rainfall and the difference between the height of the bunds and the water depth prior to the rainfall. The tritium injection method of Munnich (1968) was used to calculate drainage (D) below the root zone. Tritiated water was injected at 60 cm depth at the time of sowing DSR or transplanting. The change in soil water content (ΔSWC) was calculated from bulk density and gravimetric SWC to a depth of 60 cm before establishment and after harvest.

Input water productivity
Input water productivity (WP_{I+R}) was computed as the ratio of grain yield (14% moisture) to the total water input (irrigation + rainfall) and expressed as g/kg.

Results
The total amount of rainfall was 28 % higher than the long term average (586 mm) and well distributed, especially in the first 3 months of crop growth (Figure 1)

There was a significant interaction between EM and IS on the amount of irrigation (Table 1). Irrigation water input was similar in the daily irrigated PTR and DSR, but significantly lower in all AWD DSR treatments than in AWD PTR. At 20 kPa this resulted in a 485 mm (53%) irrigation water saving. Within EM, irrigation amounts in all AWD treatments were similar because of the good rainfall distribution. The difference in the irrigation water was use mainly due to recommended practice of continuous flooding in PTR for first 15 days after transplanting.

Deep drainage below 0.6 m in DSR was significantly higher than in PTR. This was probably because the soil was not puddled and because of the longer duration of DSR in the field, and some large rains between sowing and the time of transplanting. Deep drainage was significantly higher with daily irrigation (662 mm) than with AWD (175-227 mm).

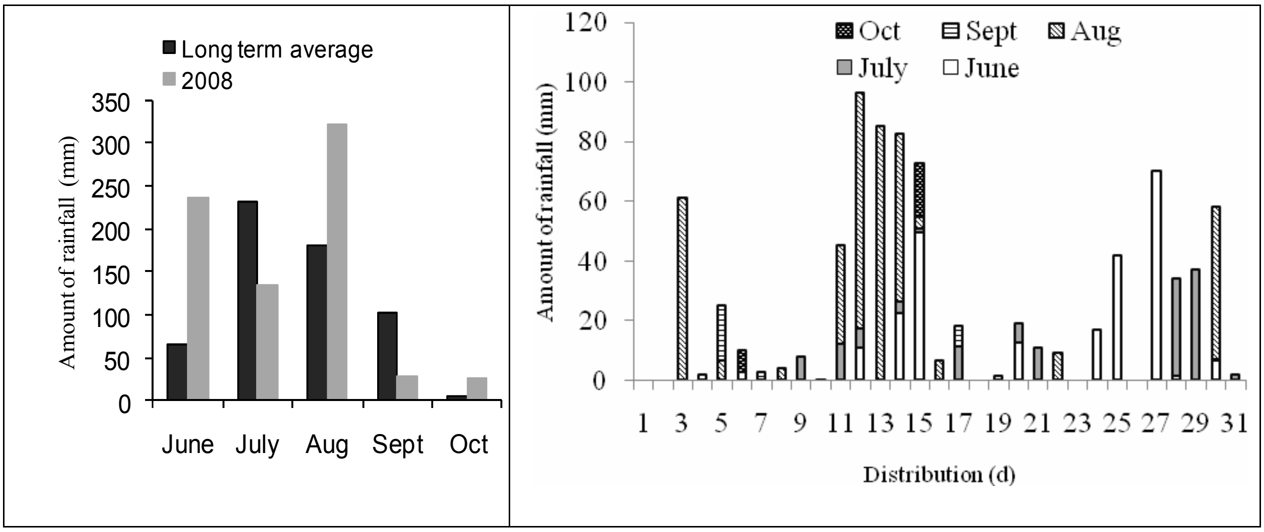

Figure 1. The amount (mm) and distribution (d) of the rainfall during rice season in 2008.

Table 1. Water balance components in dry seeded and puddled transplanted rice.

Establishment method (EM)	Irrigation scheduling (IS)	Water Balance Components (mm)							WP_{I+R} (g/ kg)
		Irrigation	Rainfall	Deep drainage below 0.6 m	Seepage	Runoff	ΔSWC (0-0.6 m)	ET	
PTR	Daily	2093	566	559	823	489	32.1	756	0.28
	20 kPa	1010	566	170	580	161	2.1	663	0.50
	40 kPa	960	566	141	580	161	1.5	643	0.44
	70 kPa	960	566	147	580	161	1.5	636	0.35
	Mean	1255	566	254	641	243	9	675	0.39
DSR	Daily	2212	822	982	491	585	54.8	921	0.24
	20 kPa	475	822	284	227	165	10.7	610	0.71
	40 kPa	425	822	273	227	165	4.4	577	0.40
	70 kPa	358	822	203	227	165	4.4	580	0.35
	Mean	868	822	436	293	270	19	672	0.43
Mean of PTR and DSR	Daily	2153	694	771	657	537	43	839	0.26
	20 kPa	743	694	227	404	163	6	637	0.61
	40 kPa	693	694	207	404	163	3	610	0.42
	70 kPa	659	694	175	404	163	3	608	0.35
LSD ($p \leq 0.05$)									
EM		231.0	-	30.1	60.6	ns	5.68	ns	ns
IS		133.0	-	24.4	34.5	29.4	2.44	132	0.069
EM × IS		204.0	-	33.2	ns	41.6	3.45	127.0	0.088

The heavy rains early in the season damaged the bunds and dislodged the plastic, and the development of a high earthworm population resulted in large seepage losses up to 52 DAS. The amount of water loss by seepage was significantly higher in PTR (641 mm) because all plots were continuously flooded during this period. Seepage was significantly higher (657 mm) with daily irrigation than AWD (404 mm).

Runoff occurred during some high rainfall events, and was significantly higher (by 70%) with daily irrigation (537 mm) than AWD (163 mm). Changes in stored soil water were small relative to other components of water balance. The increase in stored soil water was significantly higher in daily irrigated DSR (55 mm) than daily irrigated PTR (32 mm), probably because of the rains before transplanting. Change in SWC of the AWD treatments was very small (2-11 mm).

There was a significant interaction between EM and IS on ET. Evapotranspiration in daily irrigated DSR (921 mm) was significantly than in any other treatment, probably because of the higher biomass production under DSR (17.0 t/ha) than in PTR (15.8 t/ha), and because DSR was exposed to a longer evaporative demand period than PTR (26 d between sowing DSR and transplanting). However ET in DSR and PTR was similar under all AWD conditions (608-663 mm).

There was no interaction effect of EM and IS on grain yield. PTR produced significantly higher grain yield as compared to DSR. Yields with daily irrigation and irrigation at 20 kPa were similar, but there was a significant decline in yield with irrigation at higher tensions. There was a significant interaction between EM and IS on WP_{I+R}, which was highest in DSR with irrigation at 20 kPa (0.71 g/kg) followed by PTR irrigated at 20 kPa (0.5 g/kg) and least in daily irrigated PTR (0.28 g/kg). The difference in WP_{I+R} between DSR and PTR at 20 kPa was largely due to reduced seepage losses and despite higher deep drainage losses in DSR, while ET and runoff were similar. At higher water tension (40 and 70 kPa) there was no significant difference WP_{I+R} between DSR and PTR because the reduced irrigation amount in DSR was offset by a similar reduction in grain yield in DSR.

Conclusion

In a year of above average and relatively well distributed rainfall, alternate wetting and drying resulted in very large irrigation water savings in both PTR and DSR, mainly due to large reductions in deep drainage, underbund seepage and runoff. Irrigation at 20 kPa soil water tension reduced irrigation input by 50% in DSR compared with PTR, while maintaining yield. As a result, input water productivity was highest (0.71 g/kg) in DSR irrigated at 20 kPa tension, and least in continuously flooded PTR (0.28 g/kg). Further evaluation is needed under a range of environmental conditions to help develop irrigation scheduling guidelines for DSR and to assess the likely nature and amount of water savings from adoption of DSR.

References

Bhushan L, Ladha JK, Gupta RK, Sing S, Tirol-Padre A, Saharawat YS, Gathala M, Pathak H (2007) Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. *Agronomy Journal* **99**, 1288–1296.

Bouman BAM (2001) Water-efficient management strategies in rice production. International Rice Research Notes 16.2, IRRI, Los Baños, Philippines, pp. 17–22.

Cabangon RJ, Tuong TP Abdullah NB (2002) Comparing water input and water productivity of transplanted and direct-seeded rice production systems. *Agricultural Water Management* **57**, 11–31.

Choudhary BU, Bouman BAM, Singh AK (2007). Yield and water productivity of rice-wheat on raised beds at New Delhi. India. *Field Crops Research* **100**, 229–239.

Munnich KO (1968) Moisture movement measurement by Isotope tagging. In 'Guide book on Nuclear techniques in Hydrology'. Pp. 112-117. (IAEA).

Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletion in India. *Nature* **460**, 999-1002.

Singh S, Malik RK, Mongia AD, Sharma RK, Sidhu BS, Bijay-Singh (2005) In 'Haryana and Punjab In: Agenda Notes: 13th Regional Technical Coordination Committee Meeting, Rice–Wheat Consortium for the Indo-Gangetic Plains, Dhaka, Bangladesh'. February 6–8, 2005, pp. 27–29.

Tuong TP, Singh AK, Siopongco J, Wade LJ (2000) Constraints to high yield of dry-seeded rice in the rainy season in a humid tropic environment. *Plant Production Science* **3**, 164–172.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.