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ARTICLE

Comparison of conventional puddling and dry tillage in rice–wheat system

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Abstract In many parts of Asia, rice is transplanted in puddled fields and after the harvest of this crop wheat is grown. This traditional method of growing rice may have deleterious effect on the growth of the subsequent crop in a rice–wheat cropping system. Wheat crop was planted in the same plots following a rice crop to evaluate the residual effects of various tillage treatments suitable for rice on the growth of the subsequent crop. Rice cultivar Super-basmati was grown in summer and wheat cultivar Auqab-2000 in autumn after rice. Four treatments were used to grow rice viz. transplanting in continuously flooded conditions (TRF), transplanting with intermittent flooding and drying (TRI), direct seeded using dry seeds (DSR) and direct seeded using primed seeds (DSP). Traditional puddling tillage system was followed in TRF and TRI, while for DSR and DSP, dry tillage system was followed. For convenience, the abbreviations of the rice treatments were used to indicate the same plots during the wheat crop. For the rice crop, tiller number, fertile tillers, kernel and straw yield, and harvest index were significantly better with transplanted treatments (TRI and TRF) than the direct seeded treatments. TRI also gave a yield advantage of 5% over TRF. For wheat, crop following direct seeded rice was better than transplanting. This study suggests that intermittent irrigation in the traditional puddling tillage system and DSP dry tillage system are the promising alternatives that may be opted.

Keywords Direct seeding · Edaphic conflict · Flooding · Intermittent irrigation · Rice–wheat system · Seed priming · Stand establishment

Introduction

Rice–wheat cropping systems occupy 24 million hectares of cultivated land in Asia. Of this, 13.5 million hectares are in South Asia extending from the Indo-Gangetic Plains to the Himalayan foothills. Rice–wheat systems cover about 32% of the total rice area and 42% of the total wheat area in these four countries: India, Pakistan, Bangladesh and Nepal (Anonymous 2007). Although the most rice–wheat cropping is fully irrigated, substantial areas are rainfed. Traditionally rice is transplanted after puddling in continuously flooded field and wheat is sown after pulverizing the soil under aerobic conditions (Singh et al. 2005), which indicates a divergence in conventional tillage system for rice and its consequent effects on the soil environment for the succeeding wheat crop (Singh et al. 2005). In rice, for example, soil puddling has been found to have several benefits related with yield, weed suppression and resource-use efficiency (Naklang et al. 1996; Surendra et al. 2001). However, there are several studies available reporting the effect of puddling on soil physical properties destructive for the performance of subsequent non-rice crop (Utomo et al. 1985; Sharma and DeDatta 1985). Poor stand establishment due to low germination rates has been linked to inadequate seed–soil contact in cloddy, post-paddy soils (Cook et al. 1995; Rahmianna et al. 2000; Ringrose Voase et al. 2000). Data from rice-based systems (Sur et al. 1981; Aggarwal et al. 1995; Ishaq et al. 2001) suggest that subsurface compaction can amplify drought probability for subsequent dry season crops by limiting root development

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at depth. On the other hand, conflicts between puddled rice and succeeding crops are not consistently observed. Hobbs et al. (2002) reported a 10% yield advantage for wheat on a silt loam soil following non-puddled rice, whereas no benefit was observed on a sandy loam. Kirchhof et al. (2000) noted that puddling reduced soybean (*Glycine max* L.) yield but did not influence productivity of mungbean (*Vigna radiata* L.) or peanut (*Aracis hypogaea* L.). Other experiments document substantial soil physical changes from puddling that did not cause growth penalties for several cereal and legume crops (e.g. Humphreys et al. 1996; Singh et al. 1996; Tranggono and Djoyowasito 1996). Much of this response inconsistency is likely related to the site-specific nature of soil puddling.

Late planting is the principal limitation to wheat productivity in many areas of South Asia (Hobbs et al. 1994; Ahmed and Meisner 1996). At best, post-rice deep tillage is an only partial solution for physical constraints to wheat performance because it does not alleviate poor tilth in the surface horizon. For most regions that utilize the rice–wheat cropping pattern, there is a general consensus that wheat yields will increase if puddling operations for rice establishment are reduced or eliminated (Fujisaka et al. 1994; Hobbs et al. 1994; Timsina and Connor 2001). The basic question is can rice culture be like wheat so that it can benefit the cropping system productivity and sustainability? Direct seeded rice is an attractive alternative in this regard (Farooq et al. 2006a), which facilitates timely establishment of rice and succeeding crops. Unlike puddled fields, direct seeded fields do not cause problems and help save irrigation water. In growing a successful direct seeded crop, weed management, and poor and erratic emergence are the issues that require serious attention (Balasubramanian and Hill 2002). Now there are several management practices available to tackle the weed problem (Rao et al. 2007). Seed priming is reported to enhance the emergence and seedling establishment of direct seeded rice in dry tillage system (Du and Tuong 2002; Farooq et al. 2006a, b). To best of our knowledge, no study has been conducted to compare the conventional puddling and dry tillage systems employing intermittent flooding and drying (in the conventional puddling system) and seed priming (in dry tillage system).

The present study was, therefore, conducted to compare the conventional puddling and dry tillage systems with intermittent flooding and drying and seed priming in the rice–wheat systems and to investigate the benefits associated with each.

Materials and methods

Site description

Two rice–wheat experiments were conducted at a farmer's farm (36.6° N, 76.6° E, 184.8 M altitude) in 2005–2006 and 2006–2007. The soil belongs to Lyallpur soil series (aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplarged in USDA classification and Haplic Yermosols in FAO classification). The experimental soil was having pH 7.85 and 7.90 and organic matter 0.70 and 0.71% before and after rice crop, respectively. The climate of the area is semi-arid with an average annual temperature of 27°C and average annual rainfall of 1,000 mm. Weather data during the course of investigation is given in Table 1.

Experimental details

Experiments were exactly the same in design and implementation in both the seasons. They were laid out in a randomized block design with three replicates and plot

Table 1 Weather data during the course of study

Months	Mean monthly temperature (°C)			Mean monthly relative humidity (%)	Total monthly rainfall (mm)
	Min.	Max.	Average		
April 2005	35.1	18.2	26.6	35	18.4
May 2005	38.1	23.4	30.8	31.6	18.4
June 2005	43.3	28.7	36	32.5	62.5
July 2005	37.1	28.3	32.7	65.8	88.0
August 2005	39.2	28.6	33.9	53.9	51.6
September 2005	37.4	26	31.7	51.8	84.6
October 2005	35.2	19	27.1	44.2	10
November 2005	29.1	12.6	20.8	50.5	0.00
December 2005	23.9	05.3	14.6	52.5	0.00
January 2006	20.8	06.3	13.5	58.1	8.2
February 2006	27.6	13.0	20.3	52.4	14.6
March 2006	28.1	14.6	21.4	40.7	37.0
April 2006	37.6	20.7	29.2	23.4	0.0

Source Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad 38040, Pakistan sizes of 10 m × 7 m. Rice (*Oryza sativa* L.) was grown in summer and wheat (*Triticum aestivum* L.) in autumn after harvesting rice. Rice cultivar Super-basmati was grown with four treatments: transplanted continuously flooded (TRF), transplanting with intermittent flooding and drying (TRI), direct seeded using dry seeds (DSR) and direct seeded using primed seeds (DSP). Traditional puddling tillage system was followed in TRF and TRI, while for DSR and DSP, dry tillage system was followed.

In the traditional puddling tillage system, four cultivations with a tractor-drawn cultivator followed by two plankings were given to achieve the desirable soil structure. Field was flooded with water and puddle conditions were created with the help of a tractor-drawn cultivator in standing water. The puddle field was left for a day or so to settle soil particles. Three-week-old seedlings were transplanted in 20 cm apart hills. For nursery raising, seeds were broadcasted in the standing water at the rate of 80 g m^{-2} in the nursery bed. Irrigation water was applied daily in the morning. Fertilizers (N, P, K and Zn) were applied at the rate of 15, 9, 8 and 2 g m^{-2}. Fertilizers used were urea (46% N), single super phosphate (18% P_2O_5), sulfate of potash (50% K_2O) and $ZnSO_4$ (35% Zn).

In dry tillage system, soil was plowed dry and harrowed before sowing seeds over a moist seed bed. Seeds (dry and primed) were drilled in 20 cm apart rows at a rate of 60 kg ha^{-1}. For priming, seeds were soaked in $CaCl_2$ solution with osmotic potential of −1.25 MPa for 24 h and were then re-dried to their original weight. This soaking and re-drying cycle was again repeated (Farooq et al. 2006a).

Fertilizers used were urea (46%), single super phosphate (18% P_2O_5), sulfate of potash (50% K_2O) and $ZnSO_4$ (35% Zn). According to soil analysis report 120 kg N, 75 kg P_2O_5, 75 kg K_2O and 10 kg Zn ha^{-1} were applied. The whole quantity of phosphorus, potash and zinc, and half of nitrogen were applied and incorporated into the soil as basal dressing during seed bed preparation. The remaining half of nitrogen was applied split into one-half at tillering and the other at the panicle initiation.

Irrigation water was applied using flexible hoses. To prevent seepage flows between plots, the flooded plots were separated by a strip of bare soil of 2 m width from the direct seeded plots.

In transplanted plots, irrigation water at the time of transplanting was maintained at 3–4 cm. In TRF, 1 week after transplanting a constant water depth of 5–6 cm was maintained to keep the field continuously flooded. While in TRI, irrigation was applied about every other day to keep the soil moist. In direct seeded treatments, irrigation water was applied at 1 week interval. Amount of irrigation water used in each treatment is given in Table 2. In all the treatment, irrigation was withheld about one week before harvesting when the signs of physiological maturity appeared.

Table 2 Amount of water used in different rice establishment methods for rice

Treatments	Amount of water used (cm)
DSR	80
DSP	80
TRI	110
TRF	130

DSR Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

For weed control in transplanted treatments, Butachlor (Machete 60 EC) was applied at the rate of 800 mL ha^{-1} 7 days after transplanting in standing water. While, in direct seeded treatments, a mixture of ethoxy sulphuran and phenoxyprop-*p*-ethyl at 200 g and 370 mL ha^{-1}, respectively was applied 20 days after sowing in saturated soil. If required, manual weeding was also done to keep the field weed free. Carbofuran (Furadan 3G) was broadcasted at the rate of 25 kg ha^{-1} before panicle initiation to protect the crop from stem borers and leaf folders.

The crop was harvested when panicles were fully ripened at approximate moisture of 23%, and each plot was threshed separately.

After harvest of the rice crop, wheat variety Auqab-2000 was sown. For convenience, we use the abbreviations of the rice treatments to indicate the same plots during the wheat crop. In all the plots, four cultivations with a tractor-drawn cultivator followed by two plankings were given to achieve the desirable soil structure and wheat was sown with a seed drill in 20 cm spaced rows. In all treatments, the seeding rate was 100 kg ha^{-1}. Fertilizers P and K were applied basally at the rate of 60 and 25 kg ha^{-1}, respectively. Nitrogen was applied at the rate of 110 kg ha^{-1}, of which 50% was applied basal, 25% at crown root initiation and 25% at flowering. Four irrigations were given to all treatments at crown root initiation, tillering, flowering and the dough stage. The crop was harvested when spikes were fully ripened at approximate moisture of 20%, and each plot was threshed separately.

Measurements

At harvesting, agronomic traits and yield components were examined following the standard procedures. From the onset of physiological maturity, growth traits were examined four times at 15-day intervals, and yield components, spike and kernel characteristics were recorded at full maturity. Leaf area was measured using a leaf area meter (LiCor, Model 3100). Leaf area index (LAI), crop growth rate (CGR), and net assimilation rate (NAR) were

Table 3 Analysis of variance of tillage systems and rice seedling establishment methods effects on the agronomic traits and yield components of rice in rice–wheat system

SOV	*df*	Mean square								
		Plant height	Tiller number	Fertile tillers	Branches per panicle	Kernels per panicle	1,000-Kernal weight	Straw yield	Kernel yield	Harvest index
Replication	2	15.44	9.25	115.75	5.42	6.25	0.063	0.81	0.377	1.005
Treatment	3	2.97	6,440.75	3928.75	0.007	4.31	0.556	1.255	1.778	6.06
Error	6	0.493	22.92	121.42	9.99	10.47	3.62	0.156	0.154	2.97

calculated using the formulae of Hunt (1978). Crop was harvested when fully ripened to determine grain and straw yield, and harvest index.

Statistical analysis

Data were statistically analyzed using the software MSTAT-C. Analysis of variance were used to test the significance of variance sources, while least significant difference (LSD) test ($P = 0.05$) and standard error were used to compare the differences among treatment means.

Results

Rice

Different tillage systems significantly affected some of the yield components of rice however others remained unaffected (Table 3). There was no effect of tillage systems on plant height, panicle branches, kernel numbers and 1,000-kernel weight (Table 3). Maximum tiller number, fertile tillers, kernel and straw yield, and harvest index were recorded in TRI that was similar to that of transplanting in continuously flooded soil (TRF) in case of tiller number, fertile tillers, straw yield and harvest index (Table 5). While minimum tiller number, fertile tillers, kernel and straw yield, and harvest index were recorded in DSR (Table 5).

Regarding growth attributes, maximum LAI was recorded in TRF that was similar to that of TRI, followed by DSP. However, minimum LAI was measured in DSR treatment (Fig. 1). Maximum CGR both pre- and pots-anthesis, was recorded in TRF treatment followed by TRI, while minimum CGR at both the crop stages was measured in DSR treatment (Fig. 2). While NAR was in the order TRF = TRI > DSP > DSR at both crop stages (Fig. 3).

Wheat

There was no affect of any rice tillage system on the plant height, spikelets numbers, number of grains per spike and 1,000-grain number of wheat (Table 4). However, other attributes were affected significantly. Maximum tiller numbers, fertile tillers and straw yield were recorded from DSR treatment that was similar to that of DSP treatments. However, maximum grain yield and harvest index were recorded from DSP treatment that was similar to that of DSR treatment (Table 6). Although, number of tillers,

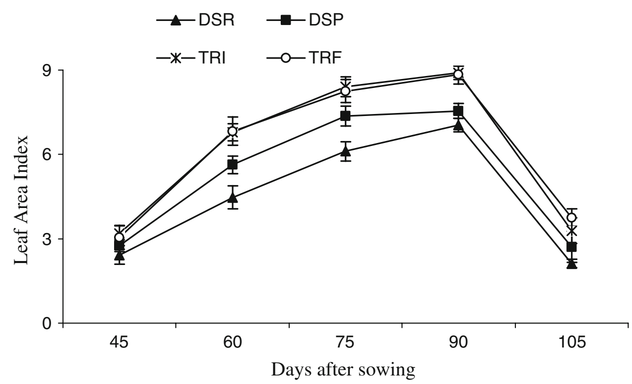

Fig. 1 Effect of tillage systems and rice seedling establishment methods on the leaf area index (LAI) of rice in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

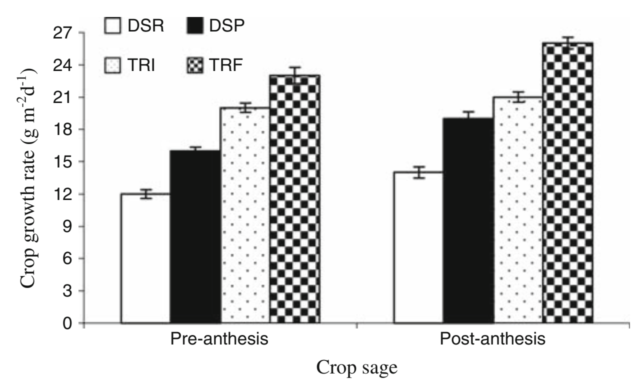

Fig. 2 Effect of tillage systems and rice seedling establishment methods on the crop growth rate (CGR) of rice in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

fertile tillers, straw yield and harvest index were similar to each other in both transplanting treatments (TRI and TRF), higher grain yield was recorded from TRI (Table 6).

Maximum LAI was recorded from DSR treatment 50, 55 and 80 DAS, at other harvests; it was similar to other treatments (Fig. 4). Both CGR and NAR for wheat were higher after anthesis than before anthesis (Figs. 5, 6). NAR was higher for DSR and DSP treatments than TRI and TRF treatments at both growth stages, whereas similar behavior in was restricted to pre-anthesis growth stage.

Discussion

This study suggests that there is a conflict between the conventional rice tillage system (where transplanting is done in continuously flooded conditions) and subsequent wheat crop. Although conventional system has yield advantage for rice (Table 5) but it reduces the yield of subsequent crop (Table 6). Transplanting rice with intermittent irrigation and avoidance of continuous flooding can improve yield (Table 5). Intermittent flooding not only reduces the water input, but also favors yield of the subsequent wheat crop (Table 6). This seems possibly due to aerobic soil conditions during the dry spell of this technique (McHugh et al. 2003) which promoted the root growth and subsequently the nutrient and water uptake and ultimately enhanced the rice growth and development. Thus, in a way reducing the deleterious effects created by puddling for the subsequent wheat crop (Sharma and DeDatta 1985; Utomo et al. 1985). Another aspect of the

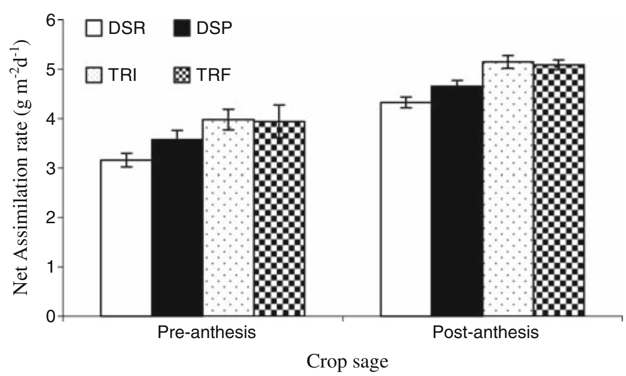

Fig. 3 Effect of tillage systems and rice seedling establishment methods on the net assimilation rate (NAR) of rice in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

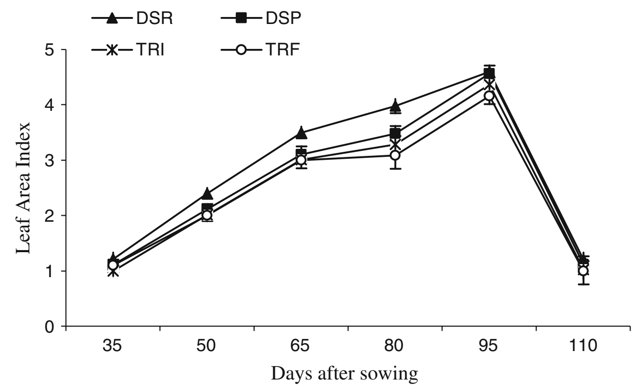

Fig. 4 Effect of tillage systems and rice seedling establishment methods on the LAI of wheat in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

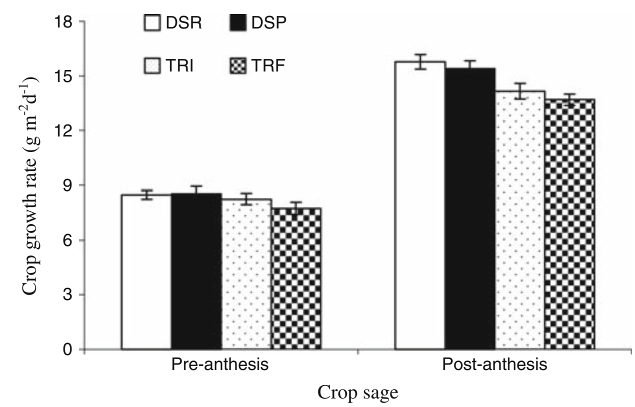

Fig. 5 Effect of tillage systems and rice seedling establishment methods on the CGR of wheat in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

Table 4 Analysis of variance of tillage systems and rice seedling establishment methods effects on the agronomic traits and yield components of wheat in rice–wheat system

SOV	*df*	Mean square								
		Plant height	Tiller number	Fertile tillers	Spikelets per spike	Grains per spike	1,000-Grain weight	Straw yield	Grain yield	Harvest index
Replication	2	0.25	30.25	12.25	20.25	5.58	0.25	0.132	0.123	3.97
Treatment	3	0.97	4,086.25	394.75	2.75	3.19	1.64	1.101	1.33	4.46
Error	6	2.14	0.25	10.25	0.917	5.36	1.81	0.337	0.098	1.91

study was that number of tillers and fertile tillers were lower in wheat crop following the transplanting treatments (although the problem was less severe with intermittent irrigation; Table 6). This might be the result of poor germination and subsequent stand establishment possibly owing to inadequate seed–soil contact in cloddy, post-rice soils (Ringrose Voase et al. 2000).

Although the growth of the rice crop was better in transplanting treatments (Figs. 1, 2, 3), it was reduced in the subsequent wheat crop following the same treatments compared with the direct seeded treatments (Figs. 4, 5, 6).

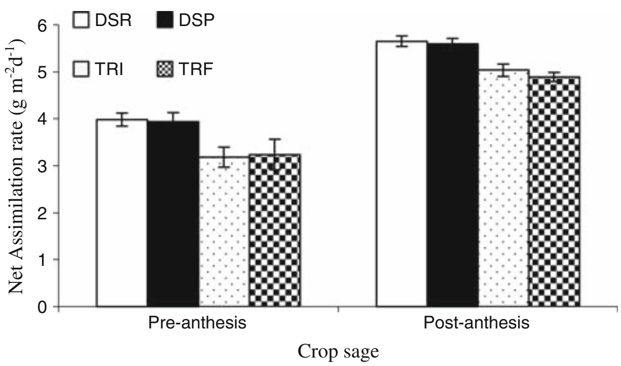

Fig. 6 Effect of tillage systems and rice seedling establishment methods on the NAR of wheat in rice–wheat system ± SE. *DSR* Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

The performance of rice in the dry tillage systems was relatively poor than the transplanted ones (Table 5). However, a significant finding was that performance of direct seeded rice was improved by employing seed priming techniques (Table 5) that seems to be the result of more vigorous and uniform emergence and seedling establishment (Hampton and Tekrony 1995; Ruan et al. 2002; Zheng et al. 2002). Seed priming either induces the de novo synthesis or increased the activities of existing enzymes (Sung and Chang 1993; Lee and Kim 2000; Basra et al. 2005), thereby producing germination metabolites in requisite amounts contributing towards the improved germination and stand establishments (Farooq et al. 2006a, b). Performance of wheat following dry tillage system in rice (direct seeding treatments) was far better than the conventional puddling (transplanting treatments; Table 6) which supports the assumption that edaphic conflict exits between rice flooding and subsequent wheat crop in rice–wheat cropping system. Moreover, there was about 40% water saving in rice grown following dry tillage system (Table 2).

Conclusion

This study suggests that there exists an edaphic conflict between conventional flooded rice culture and subsequent wheat crop in rice–wheat cropping system, which must be

Table 5 Effect of tillage systems and rice seedling establishment methods on the agronomic traits and yield components of rice in rice–wheat system

Treatments	Plant height (cm)	Tillers (m^{-2})	Fertile tillers (m^{-2})	Branches/ panicle	No. of kernels/ panicle	1,000-Kernel weight (g)	Straw yield (t ha^{-1})	Kernel yield (t ha^{-1})	HI (%)
DSR	83.67a	673c	566c	19.11a	87.66a	17.66a	8.70c	3.12 d	26.39c
DSP	84.33a	729b	607b	19.08a	88.00a	17.33a	9.42b	3.56c	27.42b
TRI	86.00a	779a	645a	19.07a	90.00a	18.00a	10.17a	4.28a	29.61a
TRF	85.00a	760a	640a	19.00a	87.33a	17.00a	9.95a	4.07b	29.02a

Means sharing the same letters in a column do not differ significantly at $P = 0.05$

DSR Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil

Table 6 Effect of rice seedling establishment methods on the agronomic traits and yield components of wheat in rice–wheat system

Treatments	Plant height (cm)	Tillers (m^{-2})	Fertile tillers (m^{-2})	Number of spikelets/spike	No. of grains/spike	1,000-Grain weight (g)	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	HI (%)
DRS	92.11a	588a	443a	15a	49.33a	33.67a	9.54a	4.43a	31.71a
DRP	91.66a	585a	441a	16a	47.00a	32.33a	9.47a	4.46a	32.01a
TRI	92.33a	528b	425b	17a	47.00a	34.00a	9.27b	3.98b	30.03b
TRF	93.00a	518b	420b	15a	48.33a	33.00a	9.15b	3.84c	29.56b

Means sharing the same letters in a column do not differ significantly at $P = 0.05$

DSR Direct seeded using dry seeds, *DSP* direct seeded using primed seeds, *TRI* transplanting with intermittent flooding and drying, *TRF* transplanting in continuously flooded soil resolved to improve the performance and sustainability of rice–wheat system. Intermittent irrigation in the conventional puddling (transplanting) system and DSP (in dry tillage system) are the promising alternatives that may be opted.

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