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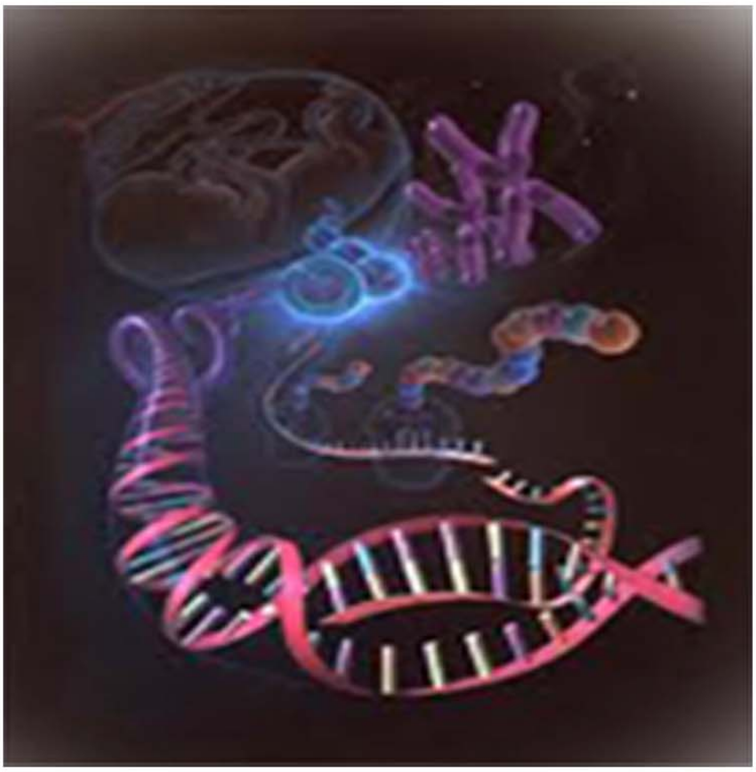

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Research Paper

CROP ESTABLISHMENT,TILLAGE AND WATER MANAGEMENT TECHNOLOGIES ON CROP AND WATER PRODUCTIVITY IN RICE-WHEAT CROPPING SYSTEM OF NORTH WEST INDIA

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Rice receives a large amount of water during land preparation and the growing period, causing poor crop water productivity and lower net benefits. In wheat, excessive tillage operations delay its sowing, resulting in low yields and net returns. Dry seeding of rice and zero tillage in wheat can be expected to reduce water inputs and tillage costs compared with the conventional system of rice-wheat cultivation. This article considers practices that would sustain higher and more stable yields for the rice-wheat system of the region. Farmer's participatory trials were conducted in the North West India for 3 years to evaluate various tillage and crop establishment systems for their efficiency in labor and water, and economic profitability. Yields of rice in conventional puddled transplanting were higher as compared to, unpuddled transplanting, reduced-till transplanting, and direct-seeding systems. Yields of wheat following both conventional or alternative tillage and crop establishment were also equal. Laser-aided land leveling had a significant effect on reducing irrigation water use in rice. Dry-direct seeding and zero-tillage rice-wheat system had a savings in labor and machine use. Zero-tillage transplanted and dry-direct-seeded rice followed by zero-till wheat had a higher net return than the conventional system. The study showed that conventional practice of puddled transplanting could be replaced by unpuddled and zero-till-based crop establishment methods to save water and labor and achieve higher income.

Keywords: Resource-conserving technologies,Crop establishment methods,Water productivity

INTRODUCTION

Traditionally in this region, farmers grow rice in the wet (monsoon) season after intensive dry and wet tillage (puddling), followed by wheat in the dry (winter) season after intensive dry tillage. But the traditional tillage and crop establishment methods create problems in timeliness of wheat seeding, maintenance of soil structure, and management of irrigation, weeds, and other pests, fertilizers, and crop residues (Rao *et al.,*

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2007). Pathak *et al.* (2003) reported yield losses of 35 to 60 kg d^{-1} ha^{-1} from the north western to eastern IGP due to delayed wheat planting. Soil quality degradation has occurred because soils for both crops are managed differently. For rice, soil is puddled (wet tillage) and kept under continuous submergence. In contrast, wheat is grown in upland well-drained soils having good tilth. Puddling reduces weed competition and water losses but destroys soil structure and creates a hard pan at shallow depth and consumes a large quantity of water (Sharma *et al.,* 2002). Poor tilth, restricted drainage, and inadequate soil aeration caused by puddling are the major limitations for wheat to express its yield potential in postrice soils. Conventional practices have further led to (1) a decline in soil carbon to as low as 0.2; (2) an increase in soil compaction; and (3) creation of a hard pan (Sharma *et al.,* 2002). Rice is the largest user of fresh surface water bodies and has led to an increase in tubewells of 480% in the past four decades in the region (Central Groundwater Board, Northwestern Region). Poor-quality irrigation systems and a greater reliance on ground water have led to problems of waterlogging, salinity, sodicity, hydraulic imbalance, and water-table decline of 0.1 to 1.0 m y^{-1} in the western IGP, resulting in a scarcity and higher cost of pumping water. Moreover, timely labor availability and increasing labor costs are becoming a serious concern for the timely planting of crops (Ladha *et al.,* 2003). In the changing climatic conditions, increased night temperature at the flowering stage causes spikelet sterility in rice and a reduction in yield of about 5% per degree Celsius rise above 32^{0}C (Peng *et al.,* 1999). The luxurious environment of excessive nitrogen and moist conditions provides a paradise for insect pests and diseases in the region and also decreases input-use efficiency. Evaluation and promotion of integrated crop and resource management in the rice-wheat system in north west India. Total Factor Productivity (TFP) has declined by 50% in the region, and a shift in weed flora and herbicide-resistant weeds are some of the major causes of the decline in TFP (Ladha *et al.,* 2003). Problems in the RWCS have been further intensified by planners and policymakers who have provided high subsidies for power, fertilizer, and irrigation. This has not only led to an overuse of these resources, but has also discouraged voluntary crop diversification. Despite the ecological damage, farmers continue to grow rice and wheat due to government support in terms of an assured minimum price for crops, ever-increasing demand, mechanization of the system, and assured irrigation. But concerns are growing about the sustainability of the RWCS as the growth rates of rice and wheat yields are either stagnant or declining.

The North West India, which serves as India's food basket, may become food-insecure in the near future. Therefore, the need is urgent to develop innovative alternative strategies for the future transformation of the irrigated rice-wheat system toward improved practices, ones that (1) are more resource-use-efficient, (2) lead to food security, (3) are economically sustainable, and (4) help in adaptation to climate change. Conservation Agriculture (CA)-based Resource Conserving Technologies (RCTs) include any new technologies (cultivars; more efficient implements; reduced or minimal tillage; soil, water, and crop management practices) that are more efficient, use less inputs, improve production and income, and attempt to overcome emerging problems (Gupta and Seth, 2007). RCTs involving no or minimum tillage with direct seeding, and bed planting; innovations in residue management to avoid straw burning; and crop diversification need to be advocated as alternatives to the conventional rice-wheat system for improving productivity and sustainability (Gupta *et al.,* 2003). Alternative methods have been proven effective to sustain soil health and reduce water demand in the rice crop in on-station trials in different agroecological regions by many scientists (Ladha *et al.,* 2003). But the application of these new tillage and crop establishment methods needs to be tested on a wider scale for water, labor, and energy efficiency in farmer-managed trials. Therefore, systematic studies were conducted with a wider approach of on-station and farmer participatory trials to develop and accelerate productivity-enhancing, input (water, labor, and energy)-efficient, soil- and environment-friendly, and profitable RCTs in the North West India.

MATERIALS AND METHODS

Site Characteristics

Fifteen farmers were selected to conduct on-farm demonstrations of RCTs in three districts (Meerut, Muzaffarnagar and Saharanpur) of western Uttar Pradesh (UP), India (28°402 073N to 29°282113N, 77°282 143E to 77°442183E). The climate of the area is semiarid, with an average annual rainfall of 665 mm (75-80% of which is received during July to September), minimum temperature of 0-4^{0}C in January, maximum temperature of 41-45^{0}C in June, and relative humidity of 67-83% during the year. The soils are generally sandy loam to loam in texture and low to medium in organic matter content. Groundwater pumping is the predominant method of irrigation. Western UP has a diversified cropping system, with RW as the dominant cropping system. Wheat is grown by broadcasting after four to five dry-tillage operations and rice seedlings (3-4 weeks old) are transplanted in puddled fields after three to four dry-tillage operations.

Experimental Layout and Treatments

On-farm trials were conducted in the RW system in three districts of western Uttar Pradesh from 2008-09 to 2010-11 in the juridiction of Sardar Vallabhbhai Patel University of Agriculture &Technology Meerut, UP, India. These trials were researcher-designed and farmer-managed, with a single replicate, repeated over many farmers. The experimental design was Randomized Block Design in which the number of treatments varied from farmer to farmer, with the farmer as a replicate /block. A combination of ten tillage and crop establishment techniques. 1. Puddled transplanted rice(CT-TPR)- zero till wheat planted by turbo happy seeder (ZT-DSW), 2. zero tillage direct seeded rice (ZTDSR)-zero till wheat (ZT-DSW), 3. conventional tillage direct seeded rice (CTDSR)-reduced till wheat (RT-DSW), 4. reduced tillage direct seeded rice (RT-DSR)-zero till wheat (ZT-DSW), 5. reduced tillage unpuddled transplanted rice (RT-TPR)-zero till wheat (ZT-DSW), 6. direct seeded rice on narrow raised beds (N Bed DSR)-zero till wheat on permanent narrow raised beds (NBed ZT-DSW), 7. transplanted rice on narrow raised beds (NBedTPR)-zero till wheat on permanent narrow raised beds (NBed ZT-DSW), 8. direct seeded rice on wide raised beds (WBed DSR)-zero till wheat on permanent wide raised beds (WBed ZT-DSW), 9. transplanted rice on wide raised beds (WBedTPR)-zero till wheat on permanent wide raised beds (WBedZT-DSW), 10. Conventional puddled transplanted rice (CT-TPR)-Conventional tillage wheat(CT-BSW) in RW system]. The details of the treatments depicted as (Table 1).

Laser-Aided Land Leveling (LL)

For laser-assisted precision land leveling, the land was first plowed at the optimum moisture level (field capacity) with a harrow/cultivator for pulverization and was leveled using a laser-equipped drag scrapper (TrimbleTM, USA) with an automatic hydraulic system attached to a 50-60 HP tractor. Before running the laser leveler, the field was surveyed at 3-m distance to record the elevation and the elevation points were averaged to know the desired elevation for leveling the field. The average elevation value was entered into the digital control box for controlling the scrapper at the desired elevation point (Naresh *et al.,* 2011) and the tractor was run across the field till the desired elevation was achieved throughout the field (Rickman, 2002).

Seeding and Seed Rate

Pusa Sugandha- 4 (1121) rice variety was seeded on 1st and 3rd June in direct-seeded plots, where as transplanting was done on 21st, 22nd and 24th June in 2008, 2009 and 2010, respectively. Rice was seeded in flat beds as well as in raised beds

Table 1: Description of Cropping Practices

Treatment Code	Rice	Wheat	Rice		Wheat	
			Tillage	Transplanting	Tillage	Drill
T_1	CT-TPR	ZT-DSW	Dry and wet tillage (puddling)	Transplanting (TPR)	Zero-tillage (ZT)	Drill seeding (DSW)
T_2	ZTDSR	ZT-DSW	Zero-tillage (ZT)	Drill seeding (DSR)	Zero-tillage (ZT)	Drill seeding (DSW)
T_3	CTDSR	RT-DSW	Conventional tillage (CT)	Drill seeding (DSR)	Reduced tillage (RT)	Drill seeding (DSW)
T_4	RTDSR	ZT-DSW	Reduced tillage (RT)	Drill seeding (DSR)	Zero-tillage (ZT)	Drill seeding (DSW)
T_5	RT(UP)TPR	ZT-DSW	Reduced tillage unpuddled (RTUP)	Transplanting (TPR)	Zero-tillage (ZT)	Drill seeding (DSW)
T_6	NBed-DSR	NBedZT-DSW	Narrow raised beds (NBed)	Drill seeding (DSR)	Narrow raised beds Zero-tillage (ZT)	Narrow raised beds (DSW)
T_7	NBed-TPR	NBedZT-DSW	Narrow raised beds (NBed)	Transplanting (TPR)	Narrow raised beds Zero-tillage (ZT)	Drill seeding (DSW)
T_8	WBed-DSR	WBedZT-DSW	Wide raised beds (WBed)	Drill seeding (DSR)	Wide raised beds Zero-tillage (ZT)	Drill seeding (DSW)
T_9	WBed-TPR	WBedZT-DSW	Wide raised beds (WBed)	Transplanting (TPR)	Wide raised beds Zero-tillage (ZT)	Drill seeding (DSW)
T_{10}	CT-TPR	CT-BSW	Dry and wet tillage (puddling)	Transplanting (TPR)	Dry conventional tillage (CT)	Broad-casting

Note: Site characteristics

after seed priming (soaking seeds in water for 12 h followed by air drying). A seed rate of 25 kg and 20 kg ha^{-1} was used for direct-seeded rice on flat and raised beds, respectively. 'PBW 343' wheat was seeded on 7th, 9th and 12th November 2008, 2009 and 2010, respectively. A seed rate of 80 kg ha^{-1} was used in treatments where wheat was seeded on beds, and 100 kg ha^{-1} was used in the rest of the treatments. The multi crop zero till cum raised bed planter with enclined plate seed metering device machine was calibrated every time before seeding to adjust the seeding rate.

Fertilizer Application

For rice, 120 kg N, 60 kg P_2O_5, 40 kg K_2O, and 20 kg $ZnSO_4$ ha^{-1} and for wheat 150 kg N, 60P_2O_5, 40 kg K_2O ha^{-1} was applied. Half dose of N and full doses of P, K, Zn was applied as basal and remaining N was applied in two equal splits in rice and in wheat, 80% N was applied as basal and remaining N was applied at full bloom stage.

Water Application and Productivity

Irrigation water was applied using 5-cm-diameter pipes and the amount of water applied to each plot was measured using a flow meter. The quantity of water applied and the depth of irrigation were computed using the following equation:

Depth of water applied (mm)

$$= [(L/1,000)/A)]/1,000 \quad ...(1)$$

where L is the amount of irrigation water (L) applied to each plot during each irrigation and

A is the area of the plot (m^2).

Rainfall data were recorded using a standard rain gauge installed within the meteorological station The total amount of water applied was computed as the sum of water received through irrigations and effective rainfall considering 80% of the total precipitation during the cropping season. Irrigation Water Productivity (WPI) was computed as the ratio of average grain yield

Apparent Nutrient Balance

Nutrient balance was calculated using different inputs and outputs measured during the study. Average crop yields were considered for nutrient balance estimation. The NP and K balance were determined as follows:

N balance = fertilizer N inputs – N uptake in grain + straw

P balance = fertilizer P inputs – P uptake in grain + straw

K balance = fertilizer K inputs – K uptake in grain + straw

Harvesting

At maturity, rice and wheat were harvested and the grain and straw yields were determined from an area of 71.4 m^2 in flat beds and 75.04 m^2 in raised beds located in the center of each plot out of 120 m^2 gross plot area. The grains were threshed using a plot thresher, dried in a batch grain dryer, and weighed. Grain moisture was determined immediately after weighing. Grain yields of rice and wheat were reported at 14 and 12% moisture content, respectively. Straw weight was determined after oven-drying at 70^0C to constant weight and expressed on an oven dry-weight basis.

Economic Analysis

The cost of cultivation was calculated by taking into account costs of seed, fertilizers, biocide, and the hiring charges of labor and machines for land preparation, irrigation, fertilizer application, plant protection, harvesting, and threshing, and the time required per hectare to complete an individual field operation. Cost of irrigation was calculated by multiplying time (h) required to irrigate a particular plot, consumption of diesel by the pump (L h^{-1}) and cost of diesel The prices of human and machine labor, and diesel are their current prices in north India collected by market survey. Gross income was the minimum support price offered by the Government of India for rice and wheat. Net income was calculated as the difference between gross income and total cost. System productivity was calculated by adding the grain yield of rice and wheat.

RESULTS AND DISCUSSION

Changes in productivity and net income in rice and wheat with RCTs vis-à-vis farmers' practices.

Performance of Rice

Rice consumes about 80% of the total water applied in the rice-wheat system and requires extensive tillage, including puddling, to establish the crop. On-farm research therefore aimed at minimizing tillage and/or eliminating puddling and saving water in rice cultivation with a minimum or no penalty on rice yield and net income. So, calculated changes in crop yields, water application and net income with an improved technology compared with the corresponding farmers' practice. Results showed that laser-leveling reduced the total (irrigation+rainfall) water use by 345 mm ha^{-1} and increased rice yield by 0.45 t ha^{-1}, than with traditionally leveled fields (Table 5). Reductions in grain yield were noted for reduced-till and zero-till direct-seeded rice (RT/ZT-DSR) and bed-planted (transplanted and direct-seeded) rice (Bed-TPR or Bed-DSR), despite significant savings in irrigation and total water use (Table 5). However, the yield penalty

Table 2: Productivity of RW Under Various Tillage and Crop Establishment Techniques

Treatment	Grain Yield (tonnes ha^{-1})								
	Rice			Wheat			R W System		
	2008	2009	2010	2008-09	2009-10	2010-11	2008-09	2009-10	2010-11
T_1	5.65	5.75	5.35	5.05	5.10	5.07	10.70	10.60	10.42
T_2	4.85	4.65	4.45	5.25	5.40	5.45	10.10	10.05	9.90
T_3	4.60	4.75	4.25	5.35	5.25	5.30	9.95	10.00	9.55
T_4	4.65	4.70	4.35	5.40	5.45	5.35	10.05	10.15	9.70
T_5	4.95	4.85	4.65	5.30	5.15	5.25	10.25	10.00	9.90
T_6	3.90	3.85	3.75	5.35	5.25	5.30	9.25	9.10	9.05
T_7	4.35	4.60	4.50	5.45	5.30	5.55	9.80	9.90	9.85
T_8	4.75	4.50	4.65	5.55	5.60	5.45	10.30	10.10	10.10
T_9	5.05	5.15	5.25	5.40	5.50	5.35	10.45	10.65	10.60
T_{10}	5.70	5.80	5.40	4.85	4.75	4.95	10.55	10.45	10.35
C D at 5%	0.87	1.05	1.13	0.49	0.42	0.38	0.81	0.68	0.47

Table 3: Profitability of RW System Under Various Tillage and Crop Establishment Methods

Treatment	Net Returns (Rs ha^{-1})								
	Rice			Wheat			RW System		
	2008	2009	2010	2008-09	2009-10	2010-11	2008-09	2009-10	2010-11
T_1	19300	19650	18275	25350	26650	25500	44650	46300	43775
T_2	27490	24075	23390	30500	31250	31510	57990	55325	54900
T_3	23905	21520	20700	26910	26405	26650	50815	47925	47350
T_4	24075	22206	21010	27150	27410	26900	51225	49616	47910
T_5	22010	20710	20035	26900	25900	26400	48910	46610	46435
T_6	15300	13150	14810	26400	26750	26650	41700	39900	41460
T_7	17860	17710	17370	27410	26850	27915	45270	44560	45285
T_8	18225	17750	17885	28150	28225	27410	46375	45975	45295
T_9	18725	18590	18935	27725	27660	26910	46450	46250	45845
T_{10}	19475	19810	18440	23890	23850	24890	43365	43660	43330

Table 4: Water Productivity In Rice and Wheat With Various Tillage And Crop Establishment Techniques

Treatment	Water productivity (kg grain m^{-3})								
	Rice			Wheat			RW System		
	2008	2009	2010	2008-09	2009-10	2010-11	2008-09	2009-10	2010-11
T_1	0.203	0.200	0.181	1.188	1.181	1.237	0.334	0.321	0.310
T_2	0.198	0.173	0.162	1.266	1.256	1.313	0.353	0.322	0.313
T_3	0.178	0.173	0.151	1.244	1.193	1.247	0.329	0.313	0.295
T_4	0.186	0.172	0.155	1.271	1.253	1.274	0.344	0.320	0.301
T_5	0.195	0.174	0.163	1.191	1.184	1.250	0.344	0.308	0.302
T_6	0.181	0.149	0.142	1.390	1.329	1.413	0.365	0.305	0.300
T_7	0.198	0.175	0.168	1.346	1.277	1.405	0.377	0.326	0.320
T_8	0.232	0.189	0.191	1.563	1.556	1.603	0.429	0.369	0.365
T_9	0.242	0.213	0.213	1.459	1.467	1.507	0.426	0.381	0.375
T_{10}	0.205	0.202	0.183	1.061	1.022	1.112	0.326	0.313	0.305

and reduction were more under narrow raised beds than under reduced/ZT direct-seeded rice. Compared with CT-TPR, in these cases, weed pressure was high, which led to higher

Table 5: Rice and Wheat, Water Application (mm ha^{-1}) and Grain Yield (T ha^{-1}) in Laser-Leveled and Traditionally Leveled Field Under Different Tillage And Crop Establishment Methods

Practices		Rice				Wheat				RW System			
Rice	Wheat	Laser-aided land leveling		Traditional land leveling		Laser-aided land leveling		Traditional land leveling		Laser-aided land leveling		Traditional land leveling	
		Water	Yield	Water	Yield	Water	Yield	Water	Yield	Water	Yield	Water	Yield
CT-TPR	ZT-DSW	2425	6.15	2770	5.70	345	5.25	435	4.68	2770	11.40	3205	10.38
ZTDSR	ZT-DSW	2355	4.85	2585	4.45	320	5.40	410	4.80	2675	10.25	2995	9.25
CTDSR	RT-DSW	2370	4.55	2670	4.15	365	5.35	445	4.90	2735	9.90	3115	9.05
RT-DSR	ZT-DSW	2365	4.65	2680	4.20	335	5.20	425	4.75	2700	9.85	3105	8.95
RT-TPR	ZT-DSW	2395	5.45	2715	4.95	370	5.15	465	4.65	2765	10.60	3180	9.60
NBed-DSR	NBed ZT-DSW	2015	4.15	2335	3.75	305	5.30	395	4.73	2320	9.45	2730	8.48
NBed-TPR	NBed ZT-DSW	2045	4.95	2360	4.45	315	5.15	410	4.60	2360	10.10	2770	9.05
WBed-DSR	WBed ZT-DSW	1960	4.75	2265	4.30	277	5.60	355	5.05	2337	10.35	2620	9.35
WBed-TPR	WBed ZT-DSW	2025	5.45	2330	4.95	295	5.55	380	4.95	2320	11.00	2710	9.90
CT-TPR	CT-BSW	2425	6.20	2770	5.75	382	5.15	472	4.58	2807	11.35	3242	10.33

Table 6: Effect of different technology on apparent NPK balance (Kg ha^{-1}) in the rice-wheat system

Technology	Fertilizer Nutrient Applied	Uptake by Crop	Balance
1. Nitrogen			
(i) Conventional Practice	180	148	32
(ii) Recommended dose	150	126	24
2. Phosphorus			
(i) Conventional Practice	60	46	14
(ii) Recommended dose	75	58	17
3. Potassium			
(i) Conventional Practice	20	104	-84
(ii) Recommended dose	75	132	-57

investments in herbicides. Therefore, more work is needed to refine alternate tillage and crop establishment methods for rice on non puddled soil, especially to minimize weed pressure, improve crop stand, and maintain high yields (Singh *et al.*, 2008).

Performance of Wheat

In RW system, the short land preparation time between crops, excessive tillage in the traditional system, and excessive moisture delay wheat planting and reduce yields (Ladha *et al.,* 2009). Studies were conducted to evaluate alternative tillage to overcome these wheat production problems. Results indicate that yield advantage and water savings were positive in zero-till wheat (ZT-DSW), probably due to timely planting. The change in net income for ZT-DSW was three times as high as that of RT-DSW, mainly due to lower tillage cost and higher grain yield. Laser land leveling increased wheat yield by 0.57 t ha^{-1} with a savings of 90 mm ha^{-1} in total water (Table 5) wheat on wide raised beds (WBed- ZTDSW) increased yield by 0.47 t ha^{-1} with a savings of 105-117 mm ha^{-1} of total water (Table 5). By and large, alternative tillage and crop establishment technologies had better performance in wheat than in rice, which may be due to inherent differences in the agronomic adaptability of the two cereals.

Performance of the Rice-wheat System

Productivity of the RW system has been stagnant in recent years because of (1) contrasting tillage requirements for rice and wheat, (2) delayed wheat sowing, (3) poor maintenance of soil structure, and (4) poor management of irrigation water, agro-chemicals, including fertilizer, and crop residues (Ladha *et al.,* 2009). For example, the reported yield losses due to delayed wheat planting amount to 35 kg day^{-1} ha^{-1} in the north west India (Pathak *et al.,* 2003). Therefore, different combinations of new tillage, crop establishment, and irrigation practices (Tables 2 and 4) were evaluated on farm sites in the North West India to examine RW system productivity, profitability, and sustainability issues. Compared with traditional leveling, laser-assisted leveling enhanced RW system productivity by 1.02 t ha^{-1} with a savings of 435 $mmha^{-1}$ of total water per year (Table 5). Drill seeding of rice and wheat on reduced-till flat land (RT-DSR/RT-DSW) or on raised beds (Bed-DSR/Bed-DSW) saved irrigation or total water use by 62 to 532 mm ha^{-1}, but was less productive than conventional practices; yield loss was high in narrow raised bed-planted crops (Table 5). Although total productivity was less in zero-till drill-seeded rice and wheat (ZT DSR/ZTDSW: by 1.08 to 1.3 t ha^{-1}), water savings were high because of lower irrigation water need. These results are consistent with previous studies (Ladha *et al.,* 2009). This suggests a need for further research to perfect double zero-tillage systems and promising options irrigation. However, laser leveling and zero-tillage for aerobic crops such as wheat are ready for farmer evaluation and promotion in the region.

Apparent Nutrient Balance

Nutrient balances (input-output) were calculated on a RW system basis (Table 6). Although the N balance was positive in both recommended practice and conventional practices, it was misleading in the absence of data on N losses. Recommended practice had a 43% higher P balance than conventional practices. However, both an recommended practice and conventional practices had a negative K (>50 kg ha^{-1}) balance, suggesting the possibility of K mining. Bhandari *et al*. (2002) reported a highly negative K balance in the RW system. In North West India, most farmer's apply a low to moderate rate of K fertilizer to rice. In wheat, most farmers either don't apply or apply a very small quantity of K. Farmers generally remove straw from the field for animal feed and other purposes, resulting in removal of a large amount of K. Farmyard manure (FYM) is used for cooking purposes and a small amount is applied to the field. Thus, recycling of nutrient, particularly K, through straw or FYM is negligible. Considering this situation, there is an urgent need for more research on K in the RW system.

Net Returns

All the alternative tillage and crop establishment methods had higher net income compared with conventional puddled transplanted rice in all three years (Table 3). The increase in net income in ZT-DSR treatments compared with CT-TPR was Rs 4600-8015, Rs 2396-4265, and Rs 2570-4950 ha^{-1} in 2008, 2009, and 2010, respectively. In all the years similar net income was obtained from different ZT-DSR treatments. In 2009 and 2010, net income was similar in ZT and RT-DSR; however, in 2010, net income was higher (Rs 2260-2380 ha^{-1}) in ZT-DSR than in RT-DSR. In 2008, CT-DSR had Rs. 4430 ha^{-1} higher net income than CT-TPR but lower than ZT-DSR and RT-DSR treatments. The saving were mainly through reduced cost in land preparation and planting method (63-78%), irrigation water (8-24%), and labor. Rice on raised beds had the lowest returns due to low yields.

In combined analysis of three years, it was found that crop establishment cost was Rs. 4820 ha^{-1} lower in ZT-DSR than in the conventional puddled transplanted system (Table 3). However, it was about Rs 2075 ha^{-1} lower in RT (unpuddled)-DSR. The fertilizer cost of ZT-DSR and RT-DSR did not differ from those of CT-TPR. The seed cost in RT-DSR and ZT-DSR was lower by Rs. 225-450 ha^{-1}. The net income in ZT-DSR (Rs. 8340 ha^{-1}) and RT-DSR (Rs. 5190 ha^{-1}) was higher than in CT-TPR. This study showed that direct-seeded rice after ZT or reduced tillage or on unpuddled soil provided more net income than CT-TPR. Higher income was a combination irrigation and savings in production cost (crop establishment cost and seed cost). However, herbicide cost increased in these alternative methods. This suggests that weed control problems increase with the shift from puddled transplanted rice to direct-seeded rice (Kumar *et al.,* 2008). These results were evaluation and promotion of resource-conserving tillage and crop establishment techniques in the rice-wheat consistent with other findings that also found a lower production cost and higher net income in direct-seeded rice than in the conventional system (Bhushan *et al.,* 2007).

In Wheat crop establishment cost was highest in Bed- DSW and decreased in this order: Bed-DSW > CT-BSW>CT-DSW>RT-DSW,>ZT-DSW (Table 3). The cost of crop establishment was Rs. 3835, Rs. 3810, and Rs. 2020 ha^{-1} higher in Bed-DSW than in CT-BSW in years 1, 2, and 3, respectively. In contrast, the cost of crop establishment in ZT-DSW treatments was lower than CT-BSW. In 2008-09, ZT treatments (ZTDSW, RTDSW, and NBedZTDSW) and WBed-ZTDSW had higher net income than CT-BSW (Table 3). In 2009-10, net income was highest in ZT-DSW plots, followed by WBedZT-DSR and RT-DSR treatments. Wheat on beds provided additional net income of Rs. 4375 ha^{-1} compared with CT-BSW, whereas ZT-DSW treatments provided additional income ranging from Rs. 3560 to Rs. 7400 ha^{-1} In 2010-11, wheat on beds consistently had the highest net income.

Both Bed-DSW and ZT-DSW provided additional net income of Rs. 3025-6620 ha^{-1} compared with CT-BSW. In three-year combined analysis, it was found that wheat on beds provided higher net returns than CT-BCW.

The RW systems of NW India are critical to the country's food security. However, yield stagnation or decline since the 1990s, and the large gap between potential and farmer yields, are major concerns given the need to increase production to match population growth. Declining soil organic matter and soil structure as a result of puddling are likely contributors to the inability to raise yields. Furthermore, current rates of extraction of groundwater for RW systems are not sustainable, causing rapid water table decline. Use of alternative tillage and water management technologies has been proposed as a means to increase the productivity, profitability and sustainability of RW systems, principally through improving soil structure, etc., for wheat, direct drilling of both crops, and reducing irrigation requirements for both crops. Yields of wheat following both conventional or alternative tillage and crop establishment were also equal.Laser-aided land leveling had a significant effect on reducing irrigation water use in both crops. Dry-direct seeding and zero-tillage rice-wheat system had a savings in labor, input use water requirement and machine use. Conventional practice of puddled transplanting could be replaced by unpuddled and zero-till–based crop establishment methods to save water and labor and achieve higher income.

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