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Permanent beds and rice-residue management for rice–wheat systems in the North West India

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ABSTRACT

Rice–wheat (RW) cropping systems are critical for food security and livelihoods in South Asia. This is particularly so in India where 10 million hectares of rice and wheat are grown in sequence, providing 85% of the total cereal production and 60% of the total calorie intake. Over 150 million people are economically dependent on RW systems in South Asia. The area and productivity of RW systems across South Asia increased dramatically between the 1960s and the 1990s, with the rate of increase in production surpassing the rate of population increase. This Green Revolution was enabled by the introduction of nutrient-responsive improved varieties, rapid expansion of irrigation and favourable government policies. However, the sustainability of RW systems is now in question, as evidenced by many factors including yield stagnation or decline of rice or wheat across the RW systems of South Asia, soil degradation, declining groundwater levels, severe air pollution from rice stubble burning, and declining terms of trade. Around 2000 it was suggested by members of the Rice-Wheat Consortium of the Indo-Gangetic Plains,Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut,U.P.,India and others that permanent raised beds could lead to increased productivity and resource use efficiency of RW systems. A system for retaining rice residues (instead of burning) was also dearly sought. RWC commissioned a large project. Permanent beds for irrigated rice–wheat and alternative cropping systems in north-west India and Indo- Gangetic Plain-to address these questions. The project involved collaboration between Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut,RWC,CIMMYT,Mexico,IRRI,Philippines and Uttar Pradesh Diversified Agriculture Support Project (UPDASP),Lucknow.In the month of February 2004, the project team organised an international workshop at Islamabad,Pakistan, to bring together the experience and learnings of researchers working on permanent raised beds and rice-residue management for RW systems across the Indo-Gangetic Plain.The papers contained the work that was presented at the Pakistan workshop and the experience in permanent raised beds and direct drilling into rice residues for RW systems in the North West India.The papers also present important break throughs in the challenge of direct drilling wheat into rice stubbles, avoiding the need for burning and the associated air pollution and loss of organic matter and nutrients.

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INTRODUCTION

The environmental sustainability of RW systems, let alone the ability to increase production in pace with population growth, are major concerns.Symptoms of environmental degradation, which vary depending on location, include declining soil organic matter content and nutrient availability and the emergence of multiple nutrient deficiencies; increasing soil salinisation; increasing weed, pest and pathogen populations;rapidly declining groundwater levels; and particulate and greenhouse gas air pollution from stubble burning (Gulati, 1999; Pingali and Shah, 1999;Byerlee *et al.,* 2003).One of the biggest threats to sustaining and increasing the productivity of the RW systems of South Asia, especially in the north-western IGP, is water shortage. Groundwater levels are declining rapidly in north-western India (Pingali and Shah, 1999; Hira and Khera, 2000; Hira *et al.,* 2004) and water shortage during winter in Pakistan has been predicted to increase more than fourfold by 2017 (Qutab and Nasiruddin, 1994; Kahlown *et al.,* 2002). Lack of irrigation and drainage infrastructure is a major constraint to increasing production in the eastern IGP, where the ability to develop water resources for irrigation is economically limited. On top of this, the cost price squeeze of agricultural commodities has a serious impact on the

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livelihoods of the millions of farmers, labourers and others (>150 million in total) that are economically dependent on RW systems in South Asia (Ladha *et al.,* 2003). Therefore, there has been considerable research and extension effort to increase the productivity,profitability and environmental sustainability of RW systems over the past 2 decades, spearheaded by the Rice-Wheat Consortium of the Indo-Gangetic Plains, and in collaboration with the National Agricultural Research and Extension Systems (NARES).A range of technologies was developed and/or disseminated including 'zero tillage' (direct drilling), laser levelling, nitrogen management using the leaf colour chart, residue retention and raised beds.

Raised beds were introduced to RW systems of the IGP in the mid 1990s, initially for wheat, inspired by the success of irrigated maize–wheat on permanent raised beds (PRB) in Mexico (Sayre and Hobbs, 2004). Since then, many advantages of growing wheat on beds have been reported, including increased yields, reduced lodging, opportunities for mechanical weeding and improved fertiliser placement,irrigation water savings, reduced waterlogging, reduced seed rate and opportunities for intercropping (Hobbs *et al.,* 1997; OFWM, 2002; Talukder *et al.,* 2002; Hobbs and Gupta, 2003; Gupta *et al.,* 2003; Sayre and Hobbs, 2004; Ram *et al.,* 2005).Some disadvantages of raised beds for wheat were also reported, including increased powdery mildew (Sharma *et al.,* 2004) and increased salinity on sodic and saline soils (Sharma *et al.,* 2002; Yadav *et al.,* 2002). In the initial work on beds in RW systems,the beds were usually destroyed after wheat harvest prior to puddling and transplanting rice on the flat.Hobbs *et al.* (2002) and Connor *et al.* (2003) proposed PRB as a means of increasing the productivity and profitability of RW systems. They considered that PRB, in comparison with fresh beds, offered the potential additional advantages of reduced or zero tillage for both crops, with large savings in diesel,labour and machinery costs. Other potential benefits included improved soil structure for wheat through controlled traffic and minimum tillage. Importantly, permanent beds also offered the opportunity for diversificationto waterlogging-sensitive crops like oilseeds and pulses, where substantial yield gains can be realised However, Connor *et al.* (2003) also cautioned that bed systems may not be suited to some situations, such as coarse-textured soils, because of exacerbated losses by percolation in the absence of puddling. They also foreshadowed that,while PRB were likely to result in greater water and nutrient use efficiency, there would be new problems relating to weed control, and new issues concerning nutrient, residue and water management, and plant type. Sharma *et al.* (2004) also found increased problems with termites for wheat on PRB.Around the same time that PRB were being proposed,an unprecedented revolution in adoption of'zero-till' (direct-drilled) wheat after rice was underway across the IGP (Ahmad and Gill 2004; Malik *et al.,* 2004). The benefits of zero tillage included increased profitability due to fuel and time savings, increased yield (through more timely sowing and better control of *Phalaris minor* and reduced irrigation amount (Chauhan *et al.,* 2000; Malik *et al.,* 2004). However, a prerequisite for successful implementation of zero-till wheat in the north-western IGP, where most rice is combine-harvested, is burning the loose rice residues. About 90% (21 Mt) of rice straw is burnt in Western Uttar Pradesh, India, each year. In Punjab, Pakistan, more than 50% of the rice is currently combine-harvested followed by partial or complete burning, and the proportion harvested by combine is predicted to increase to 100% by 2030 (S. Kalwar, pers. comm.). The result is terrible air pollution, affecting human and animal health, disrupting vehicle and air traffic and causing accidental burning of property and remnant ecosystems. To avoid the need to burn the rice straw,improved technology with the capability of direct drilling into the standing and loose residues is needed.

In recent years the major emphasis in RW systems has been on resource conservation technologies(RCTs) for both rice and wheat to reduce the cost of cultivation and energy consumption, sustain productivity and increase the profit margin of farmers. The RCTs under investigation include reduced and zero tillage of both rice and wheat, direct (wet, dry) seeding of rice, permanent raised beds (PRB) and residue retention. Permanent raised beds for RW represent a major shift in production practices. Changing from flat to bed layouts alters the geometry and hydrology of the system and offers greater control of irrigation and drainage and their effects on the transport and transformation of nutrients and possibly better capture and use of rainfall (Connor *et al.,* 2003).Reduced tillage and dry seeding with PRB can reduce the costs of labour, diesel, machinery, wheat seed and irrigation and allow more timely crop establishment (Connor *et al.,* 2003). Hence, four studies were conducted under researcher-managed and farmer participatory trials to evaluate the productivity,profitability, water use and soil properties of RW systems using a range of tillage and crop establishment techniques including PRB.

MATERIALS AND METHODS

The name, abbreviation, brief description, benefits,

Table 1a : Name, abbreviation, brief description, main benefits, and limitations of conventional technologies and RCT's for rice

Name	Abbreviation	Brief description	Benefits	Limitations
Conventional -till (puddled) transplanted rice	CT-TPR	Land is plowed, puddled,and leveled;21- 30-d-old seedlings are transplanted at random or in rows.	Good water retention due to plowpan;fewer weeds; sustainable.	Timeconsuming; labor-intensive; delays wheat seeding in RW system; destroys soil structure.
Reduced-till (non-puddled) transplanted rice	RT?TPR	2–3 dry tillages followed by planking/ leveling and ponding water but without puddling; 21–30-d-old seedlings are transplanted at random or in rows.	Reduced tillage; good soil structure due to no puddling.	Time consuming; labor-intensive; difficult to plant manually; weed pressure
Reduced-till (non-puddled) dry drill-seeded rice	RT?DSR	Dry seeds are drilled in rows by a zero-till fertiseed-drill at 2–3-cm depth in a well-prepared moist soil and leveled, followed by one light irrigation applied for good germination.	Reduced tillage; faster crop establishment; allows timely planting; less labor; easy to weed between rows; good soil structure due to no puddling	Heavy weed infestation Requiring chemical weed control.
Reduced-till (non-puddled) dry drill-seeded rice + *Sesbania*	RT-DSR+ Ses	Rice is drill-seeded; *Sesbania* seeds either drill-seeded or broadcast in reduced-till plots followed by *Sesbania* knocked down at 25-30 DAS with 2-4,D.	Faster crop establishment ; less labor;partial weed suppression and enhanced soil fertility by *Sesbania*; good soil structure due to no puddling.	May reduce rice yields due to intercrop competition; additional cost of *Sesbania* seeds and herbicide to control *Sesbania*
Raised-bed transplanted rice	Bed-TPR	A bed former-cum-drill seeder is used to form 37-cm-wide raised beds and 30-cm-wide furrows in well-prepared, pulverized soil. Then, 21-d-old seedlings are planted on both sides of moist beds. Furrows are kept flooded for up to 21 DAT.	Good crop stand; good drainage;saving in water; facilitates mechanical weeding.	More weeds ;micronutrient deficiency; termite problems ; labor intensive.
Raised-bed drill seeded rice	Bed-DSR	A bed former-cum-zero-till drill is used to form 37-cm wide raised beds and 30-cm-wide furrows in well prepared and pulverized soil, and dry rice seeds are sown in rows on both sides of moist beds. Furrows are kept flooded for up to 21 DAS. Frequent light irrigations are applied for quick germination and crop establishment.	Good drainage; savings in water, facilitates Mechanical weeding.	Poor crop stand; heavy weed infestation requiring chemical weed control; micronutrient deficiency; termite problems; soil compaction with time.
Zero-till unpuddled transplanted rice	ZT-TPR	Transplanting rice seedlings in flooded field atoptimum soil moisture without tillage and seedbed preparation.	No tillage cost;good soil structure due to no puddling.	Difficult to plant manually; more weeds; labor intensive.
Zero-till drill seeded Rice	ZT-DSR	Fields are flush-irrigated to moisten the soil and llow weeds to germinate. After 5–7 days, glyphosate /paraquat is applied to kill all weeds. Then, a zero-till drill seeder is used to drill rice seeds at shallow depth, followed by a light irrigation to have a quick and uniform germination.	Uniform crop stand; savings on tillage cost; good soil structure for winter wheat.	Heavy weed infestation Requiring chemical weed control; micronutrient deficiency; termite problems.
Zero-till drill seeded rice and *Sesbania*	ZT-DSR+Ses	Rice is drill-seeded; *Sesbania* seeds either drill-seeded or broadcast in zero-till plots. *Sesbania* knocked down at 25–30 DAS with 2-4,D.	No tillage ;faster seeding; less labor; weed suppression by *Sesbania*.	May reduce rice yields due to intercrop competition; additional cost of *Sesbania* seeds

Table 1b : Name, abbreviation, brief description, benefits, and limitations of conventional technologies and RCTs for wheat

Name	Abbreviation	Brief description	Benefits	Limitations
Conventional-till broadcast-seeded wheat	CT-BCW	Seeds are broadcast manually in thoroughly prepared fields with 4–5 plowings/ harrowings by a tractor or a power tiller. After sowing, laddering is practiced to cover seeds.	Traditional;easy crop Establishment	High energy and tillage cost; high seed rate; late wheat seeding; low yield.
Reduced-till drill seeded wheat	RT-DSW (rotovator)	A single-pass tillage is done by a tractor with an attached rotovator or tiller; then, wheat is drill-seeded.	Faster tillage and seeding; savings on tillage cost; timely wheat seeding;high yield.	Tendency to increase tillage frequency; no soil structure maintenance.
Raised-bed drill seeded wheat	Bed-DSW	Here, a bed former-cumzero-till drill is used to form 37-cm/120cm-wide raised beds and 30-cm-wide furrows in well-prepared, pulverized soil and wheat is sown in rows on both sides/six rows of moist beds.	Good drainage; savings in Irrigation water ;facilitates mechanical weed control.	Variable crop stand; weed pressure.
Zero-till drill seeded Wheat	ZT-DSW	Glyphosate/paraquat is applied to kill all weeds and wheat seed is drilled at 4–5 cm in moist soil by a zero-till fertilizer-cum-seeddrill, without any tillage and in the presence of anchored crop residues.	Uniform crop stand; savings in tillage cost; timely wheat planting.	Chemical weed control.
Zero-till drill seeded wheat under surface mulch or crop residues	ZT-DSW Residue	The surface mulch seeder cuts stubbles, picks up combined loose straw, chops into small pieces, and spreads uniformly in the field, followed by drill seeding of wheat in rows.	Reduced cost;faster and timely wheat seeding; partial weed control due to mulch.	Variable yield.

and limitations of selected RCTs and conventional technologies are presented in Table 1a and 1 b for rice and wheat.

An experiment on different tillage and crop establishment techniques involving permanent beds were conducted under farmers participatory researcher managed trials at the Farmers field of district Ghaziabad of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (Uttar Pradesh), India juridiction (29°4'N, 77°46'E, 237 m above sea level) during 2000-04.The water table was deep at all sites (23–35 m) with very good quality groundwater which was used for irrigation. The climate of the region is broadly classified as semi-arid subtropical, characterised by very hot summers and cold winters. The hottest months are May and June when the maximum temperature reaches 45–46 °C,while in December and January,the coldest months of the year, the minimum temperature often goes below 4 °C. Average annual rainfall is 805 mm,80% of which is received through the north-western monsoon during June–September. In general the soils of the farmers' fields were sandy loams with medium fertility.The particle size distribution of the 0–20 cm soil layer is 69.2% sand, 16.1% silt and 14.9% clay. All rice yields are presented at 14% moisture and wheat yields are dry.The experiment was initiated during with the monsoon (rice) season in 2000 in collaboration with RWC and the IRRI. The experiment compared eleven treatments consisting of five tillage/ establishment methods with and without ground cover for both crops (sesbania in rice; wheat with rice residues). All treatments were tilled and/or sown with implements powered by a 45 hp four-wheel tractor, and were irrigated prior to either the first tillage operation or to seeding in the case of zero-till wheat (ZTW) and carried out at fifteen locations (one farmer at each location) in district Ghaziabad for four years.

Management of groundcover:

Sesbania (+S) in rice. In the dry-seeded rice plots sesbania was broadcast at 15 kg seed/ha on the same day or two three days after rice seeding. Fourty five days after seeding the sesbania was knock down by spraying with 2,4-D ester @ 400 g a.i./ha. In the transplanted rice sesbania was sown ex-situ on the same day as the dry seeding, and was applied as a green manure mulch (after cutting into 10–12 cm lengths) to the transplanted rice on the same day as it was sprayed in the DSR plots.

Rice residues in wheat (+R):

Rice residues (partiall anchored, partially loose) amounting to 6 t/ha were retained in the +R treatments. In the raised beds the rice residues were cut at ground level and removed before sowing, then spread uniformly as mulch after sowing. In the flat plots wheat was direct drilled into the rice residues using a double-disc drill.

Seeding and seed rate:

Pusa Basmati -1 rice variety was seeded on 1st and 3rd June in direct-seeded plots, where as transplanting was done on 22nd and 24thJune in 2000 to 2004, respectively. Rice was seeded in flat beds as well as in raised beds after seed priming (soaking seeds in water for 12 hr's 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 and 9th Nov. 2000 and 2004, 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 per cent N was applied as basal and remaining N was applied at full bloom stage.

Weed management:

The crop was maintained weed free using following practices:

Rice:

Weeds that germinate prior to seeding of rice and wheat in zero till plots were killed by spraying glyphosate @ 900 g a.i. ha^{-1}. The plots were then kept weed-free throughout the growing season. Butachlor @ 1300 g a.i. ha^{-1} at 2 days after transplanting (DAT) in case of transplanted rice followed by a spray application of bispyribac sodium(Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAT for narrow and broad leaf weeds, and pendimethalin @ 1000 g a.i. ha^{-1} at 2 DAS in direct seeded rice were applied for controlling grassy weeds followed by a spray application of bispyribac sodium(Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAS for narrow and broad leaf weeds. Additionally, 1 hand-weeding in transplanted rice and 2 hand- weeding in direct seeded rice was done to keep the plots weed-free.

Wheat:

Grassy weeds were controlled by spraying of sulfosulfuron @ 35 g a.i. ha^{-1} at 30-45 DAS, and broad leaf weeds using 2,4-D @ 500 g a.i. ha^{-1} at 35 DAS.

Maintenance of the beds:

The beds were reshaped prior to wheat sowing using the bed-planter drawn by a four-wheel tractor.

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) = ((I/1,000)/A)/1,000 [1]

where I 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

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 75.04m^2 in raised beds located in the center of each plot out of 150 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 per cent moisture content, respectively. Straw weight was determined after oven-drying at 70^{0}C 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 labour 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 (lh^{-1}) and cost of diesel. The prices of human and machine labour, 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.The changes in soil physical properties were determined on soil samples (0–15 cm) from the top (middle) of the beds in PRB and from between the rows in the flats. Bulk density was determined from undisturbed cores collected in rings at 5 cm intervals up to 20 cm soil depth. The samples were oven dried at 105^0C for 24 hours to calculate soil water content and bulk density. The plots were irrigated after harvest and soil strength was measured when soil water content was close to field capacity using a manual cone penetrometer with a 2 cm^2 cone.Soil penetration resistance was recorded every 5 cm up to 45 cm soil depth at three locations in each plot after harvest of rice and wheat crops. To determine soil aggregation, large clods were collected from each plot after harvest of the crop and sun dried, then oven dried. Large clods were broken by hand into small pieces ranging from 4.75 mm to 8 mm in size. Waterstable soil aggregates were determined by using the wet sieve procedure (Yoder method). Infiltration rate was measured using double ring infiltrometers in each plot (three replicates) after harvest of the four crop.The initial infiltration rate was measured at 5, 15, 30 and 60 minutes intervals and steady state infiltration was measured after 24 hours.

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussion have been presented under the following sub heads:

Crop yields-profitability:

Yields of zero-till and conventionally tilled dry-seeded rice and puddled transplanted rice were similar and significantly higher than yield of dry seeded rice on beds (Table 2). There was a consistent trend for lower yields with sesbania co-culture but the differences were not significant in any tillage/crop establishment treatment. Wheat yield was similar in all five tillage / crop establishment treatments, but there was a consistent trend for higher yield with rice-residue retention. The difference was significant in the case of ZT- DSW after CT- TPR. The crop residues retained as surface mulch (partially anchored and partially loose) would have helped in regulating the soil temperature and moisture, but it is assumed the greater yield response was mainly due to the aberration in weather conditions during the crop growth period (winter 2003–04 was abnormal in terms of weather). Green and Lafond (1999) reported that surface residues in a no-till system helped to buffer soil temperature and that, during winter, soil temperature (at 5 cm depth) with residue removal and conventional tillage was on average 0.29^0C lower than that with no tillage and surface retained residues. Conversely, soil temperature during summer was 0.89^0C higher under conventional tillage than the no-till situation with surface residue retained. Total system productivity was similar in all treatments except PBDSR/PBTPR without sesbania and residue retention, which had significantly lower productivity than all other treatments, including the sesbania / residues retained PBDSR/PBTPT-PBDSW, ZTDSR - ZTDSW and CTDSR - ZTDSW treatments. There was a consistent trend for higher net return for dry-seeded rice on the flat (with zero or conventional tillage), while dry-seeded rice on beds had the lowest returns, but there were almost no significant differences (Table 3). The lower net income with the beds was due to the cost of preparing the beds in the first season—further analysis spreading the cost over the life of the beds is needed. There was a consistent trend for lower net income for rice with sesbania co-culture,largely due to the trend for lower yields.There was little effect of a preceding rice treatment on net income of wheat (zero-till in all tillage / crop establishment treatments). However, there was a consistent trend for higher net income with rice residue retention in all treatments, and the differences were always significant (or almost significant in the case of CTDSR - ZTDSW). Further, the profitability of wheat was significantly higher with residue retention compared with residue removal and the difference was more under PBTPR - PB DSW compared with other practices. The maximum net income of the system was with ZTDSR-ZTW but this was only significantly higher than net income from CTTPR - ZT DSW and PBDSR - PBDSW.

Input water use and water productivity:

The input water use includes both irrigation water applied and the rain water that fell during the rice season (815 mm) and wheat season (81 mm), but not the pre-cultivation/sowing/planting irrigations. The total input water in rice varied with tillage / crop establishment treatment (Table 3) due to differences in irrigation amount. The conventional puddled transplanted rice consumed about 9% more water (2,950 mm) than dry-seeded rice (2,575 mm) with zero conventional tillage, and 18% more water than with beds (2,420 mm). Similarly, the water

Table 2 : Productivity of rice–wheat systems under various tillage and crop establishment techniques

Crop establishment		Grain yield (t/ha)		
Rice	Wheat	Rice	Wheat	RW system
CT-TPR+S	ZT-DSW+R	5.63	5.45	11.08
CT- TPR	ZT- DSW	5.72	5.05	10.77
ZTDSR+S	ZT- DSW+R	4.65	5.75	10.40
ZTDSR	ZT- DSW	4.53	5.25	9.78
CTDSR+S	RT- DSW+R	4.35	5.65	10.00
CTDSR	RT- DSW	4.51	5.30	9.81
PBDSR+S	PB-DSW+R	4.08	5.35	9.43
PBDSR	PB- DSW	4.15	5.25	9.40
PBTPR+S	PB- DSW+R	4.25	5.40	9.67
PBTPR	PB- DSW	4.35	5.15	9.50
CT- TPR	CT - BCW	5.65	4.05	9.70
C.D. (P=0.05)		1.15	0.87	0.81

CT- TPR- conventional till puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice,PBDSR-Direct seeded rice on permanent raised beds,PBTPR-Transplanted rice on permanent raised beds, +S-with Sesbania as groundcover, ZT-DSW-zero till wheat, CT- BCW-Conventional till broad cast wheat,+R-with rice residue,RTW-Reduced till wheat.

Table 3 : Profitability of rice–wheat systems with different tillage and crop establishment methods

Crop establishment		Net returns (Rs/ha)			Benefit:cost ratio		
Rice	Wheat	Rice	Wheat	RW system	Rice	Wheat	RW system
CT-TPR+S	ZT-DSW+R	20,250	27,750	48,000	1.81	2.02	1.76
CT- TPR	ZT- DSW	19,500	26,200	45,700	1.91	1.99	1.86
ZTDSR+S	ZT- DSW+R	23,250	29,250	52,500	1.20	2.01	2.18
ZTDSR	ZT- DSW	20,900	27,300	48,200	1.35	1.98	2.01
CTDSR+S	RT- DSW+R	19,300	26,725	46,025	1.40	1.96	1.98
CTDSR	RT- DSW	17,700	25,250	42,950	1.66	1.94	1.89
PBDSR+S	PB-DSW+R	15,850	27,825	43,675	1.67	1.98	1.87
PBDSR	PB- DSW	15,150	26,500	41,650	1.78	1.96	1.84
PBTPR+S	PB- DSW+R	16,725	27,900	44,625	1.65	1.99	2.08
PBTPR	PB- DSW	15,750	26,100	41,850	1.80	2.01	2.15
CT- TPR	CT- BCW	19,750	19,600	39,350	1.86	1.81	1.72

CT- TPR- conventional till puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice, PBDSR-Direct seeded rice on permanent raised beds,PBTPR-Transplanted rice on permanent raised beds, +S-with Sesbania as groundcover, ZT-DSW-zero till wheat, CT- BCW-Conventional till broad cast wheat,+R-with rice residue,RTW-Reduced till wheat.

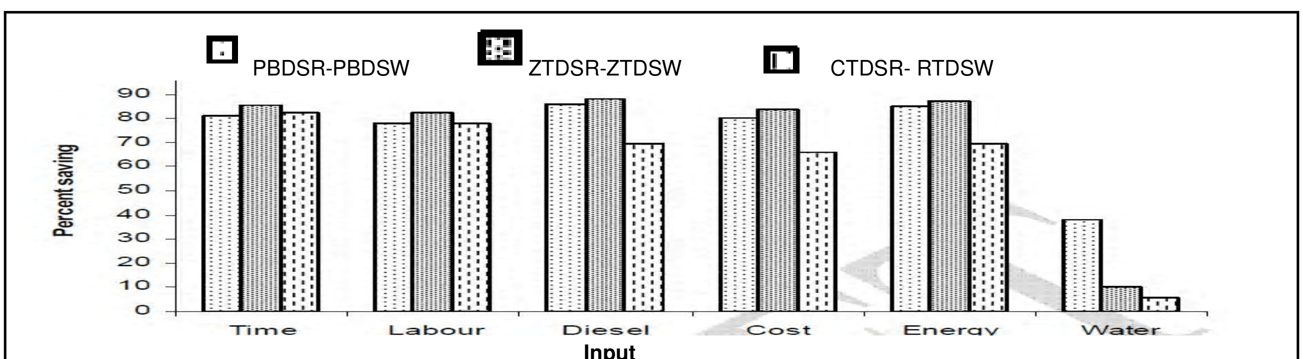

Fig. 1 : Relative saving of input use (%) over conventional practice of RW (CTTPR - CTBCW)

use in wheat on PB-DSW was 15–26% lower than with other tillage / crop establishment practices with the same rice-residue management. The higher irrigation water use in wheat with residue retention resulted from one good rainfall just before an irrigation was due in the residue removed treatments, saving one irrigation. The total system water input was least with PB- DSW and about 16% less than with CT TPR-ZT- DSW. There were no significant differences in input water productivity between any treatments for rice or the total system. However, input water productivity of wheat on PB- DSW was significantly higher than in all other treatments, with and without rice mulch. There was also a consistent trend for higher wheat input water productivity with rice-residue retention.

Input use and saving:

There were considerable savings in diesel, total cost of inputs, energy and irrigation water with double zero-till beds and flats in comparison with TPR-CTW. In PRB the savings in time, labour,diesel, cost, energy and water compared with TPR-CTW were 81%, 78%, 86%, 80%, 85% and 38%, respectively (Fig. 1).

Table 4 : Water application and water productivity in rice and wheat with various tillage and crop establishment techniques

Crop establishment		Irrigation water applied(mm ha^{-1})			Water productivity (kg grain m^{-3})		
Rice	Wheat	Rice	Wheat	RW system	Rice	Wheat	RW system
CT-TPR+S	ZT-DSW+R	2760	365	3125	0.20	1.49	0.35
CT- TPR	ZT- DSW	2950	395	3345	0.19	1.28	0.35
ZTDSR+S	ZT- DSW+R	2490	315	2805	0.19	1.83	0.37
ZTDSR	ZT- DSW	2575	385	2960	0.18	1.36	0.33
CTDSR+S	RT- DSW+R	2625	390	3015	0.17	1.45	0.33
CTDSR	RT- DSW	2675	415	3090	0.17	1.28	0.32
PBDSR+S	PB-DSW+R	2315	310	2625	0.18	1.73	0.36
PBDSR	PB- DSW	2385	325	2710	0.17	1.62	0.35
PBTPR+S	PB- DSW+R	2395	315	2710	0.18	1.71	0.36
PBTPR	PB- DSW	2420	330	2750	0.18	1.56	0.35
CT- TPR	CT- BCW	2950	445	3395	0.19	0.91	0.29

CT- TPR- conventional till puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice, PBDSR-Direct seeded rice on permanent raised beds,PBTPR-Transplanted rice on permanent raised beds, +S-with Sesbania as groundcover, ZT-DSW-zero till wheat, CT- BCW-Conventional till broad cast wheat,+R-with rice residue,RTW-Reduced till wheat.

Table 5 : Physical properties in different permanent tillage techniques after 04 years

Crop establishment		Bulk Density (mg m^{-3})	Infiltration rate (mm/hour)	Cone index	MWD (mm)
Rice	Wheat				
CT-TPR+S	ZT-DSW+R	1.62	36.3	2.78	0.39
CT- TPR	ZT- DSW	1.64	37.6	2.79	0.37
ZTDSR+S	ZT- DSW+R	1.53	52.8	2.49	0.48
ZTDSR	ZT- DSW	1.54	54.2	2.51	0.45
CTDSR+S	RT- DSW+R	1.59	57.3	2.53	0.43
CTDSR	RT- DSW	1.60	58.6	2.54	0.41
PBDSR+S	PB-DSW+R	1.57	82.6	2.57	0.54
PBDSR	PB- DSW	1.58	84.7	2.58	0.52
PBTPR+S	PB- DSW+R	1.55	78.3	2.59	0.42
PBTPR	PB- DSW	1.56	79.8	2.60	0.40
CT- TPR	CT- BCW	1.66	33.4	2.83	0.29
Initial		1.52	-	2.28	0.35
C.D. (P=0.05)		0.07	11.32	0.16	0.78

CT- TPR- conventional till puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice,PBDSR-Direct seeded rice on permanent raised beds,PBTPR-Transplanted rice on permanent raised beds, +S-with Sesbania as groundcover, ZT-DSW-zero till wheat, CT- BCW-Conventional till broad cast wheat,+R-with rice residue,RTW-Reduced till wheat.

Soil physical properties:

After four crop cycles the soil physical properties (bulk density, mean weight diameter of aggregates, infiltration rate, cone index) in the surface (0–15 cm) layer showed significant treatment differences (Table 5). The mean weight diameter of aggregates (MWD) was significantly higher in the double no-till systems (0.41 mm, 0.58 mm) than the initial value of 0.35,and declined significantly to 0.23 mm in the tillage treatments. However, MWD in the puddled and dry tilled treatments was similar. Infiltration rate in permanent raised beds was more than double that in CTTPR-CT- BCW, and almost double that in the flat DSR treatments. Infiltration rate with double zero tillage was similar to that with dry tillage. Infiltration in the flat DSR treatments was significantly higher than in CTTPR-CTBCW. Bulk density of the surface layer (0–15 cm) under double no-till did not change over the initial value, but under conventional dry and wet-tillage practices it increased significantly. The mean cone index (0–40 cm) increased significantly in all treatments but by significantly more under the conventional tillage systems.

Conclusion:

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 permanent raised beds has been proposed as a means to increase the productivity, profitability and sustainability of RW systems, principally through improving soil structure and drainage for wheat, direct drilling of both crops, and reducing irrigation requirements for both crops through furrow irrigation. The benefits of growing wheat on beds compared with conventional tillage include similar or higher yields and reduced irrigation applications.Given the low organic matter status and coarse texture of the soils of NW India, long-term evaluation of permanent bed RW systems, including organic matter and stubble management, is urgently needed.The performance of rice on beds in NW India has been variable, but generally disappointing to date. Even with similar irrigation scheduling, yields of TRB on permanent beds are generally 20–25% lower than PTR despite similar soil water tensions at 10–15 cm depth. Yield loss with DSRB is even higher (30–40%), with serious problems of iron deficiency,weeds, variable sowing depth and sometimes nematodes. Strategies for overcoming all these problems are urgently needed, as is breeding and selection for rice grown in aerobic soil and for wide row spacings between beds. Irrigation and soil management strategies to reduce potential bypass flow losses through macropores such as rat holes and cracks may need to be included in designs for rice on permanent beds.

Studies on the impacts of water management on irrigation water use in PTR in NW India have been done in small plots, where edge effects (seepage losses under and adjacent to the bunds) can dominate the water balance. There is an urgent need to evaluate the impact of water management and bed systems in full-size farmer fields, where edge effects are much smaller and irrigation times (and opportunity for deep drainage losses) are realistic. An important part of this evaluation is the quantifi cation of components of the water balance. This is needed to assess the potential for real water savings (reduced unrecoverable losses) as opposed to simple energy savings due to reduced deep drainage losses to the groundwater, from where the water can be recovered by pumping.

There are many challenges to be overcome to develop profitable, productive permanent raised bed RW systems in NW India. The development and evaluation of strategies to overcome the problems is still in its infancy. Approaches to build up soil organic matter to help improve soil structure and fertility are needed, as is long-term evaluation. The potential gains from being able to direct drill both crops,and the opportunity for fl exibility and diversifi cation in response to market opportunities, are worthy of serious pursuit.

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