Water Productivity in Cropping Systems Alternate to Rice-Wheat under Conservation Agriculture Practices

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ABSTRACT

Identification of a cropping system (CS) alternate to rice-wheat system in the Indo-Gangetic Plains under conservation agriculture (CA), which can improve crop and water productivity, is needed. Therefore, the experiment was undertaken at IARI farm, New Delhi in collaboration with CIMMYT-India during Kharif and Rabi season of 2011-12 and 2012-13 on a sandy clay loam soil. Treatments comprised of 3 cropping systems, viz., cotton-wheat (C-W), pigeon pea-wheat (P-W), maize-wheat (M-W) and 7 tillage-and residue-management practices, viz., conventional till flat-sown, zero-till (ZT) permanent narrow bed (PNB), zero-till permanent broad bed (PBB) with residue (R), zero-till flat bed with R, zero-till flat bed conventional (flat sowing after normal tillage), laid-out in a split-plot design with three replications. Results revealed that in all cropping systems, system water productivity (SWP) was highest in zero-till broad bed with residue. Among CSs, C-W resulted in higher water and system productivity compared to P-W and M-W systems. It was found 60.3, 67.9 and 63.5% irrigation water savings whereas total water savings of 49.4, 56.1 and 58.7% in C-W, P-W and M-W CSs, respectively and 215.4, 172.5 and 150.8% higher SWP compared to conventional till transplanted rice-wheat system. PBB + R and ZT + R technologies have a wide scope for adoption in these cropping systems in this region and similar agro-ecological conditions, as both technologies had much higher system grain and water productivities compared with farmers' practice.

I INTRODUCTION

Water is a critical input for sustainable agriculture, which consumes more than 80% of available water resource. With increasing demand from other sectors, availability of water to agriculture is going to decline. By 2025, two-thirds of the world's population could be under "stress conditions" (500-1000 m^3/year/capita), and 1800 million people are expected to be living in countries or regions with "absolute water scarcity" (<500 m^3/year/capita). But the fact is that 1% of water productivity gain in agriculture means 10% increase of availability for other uses. The pressure to reduce water use in irrigated agriculture is mounting, especially in Asia where it accounts for 90% of total diverted fresh water. Worldwide, rice area is estimated to be 150 Mha, 50% of which is irrigated. It consumes about 70% of the available irrigation water in India (Biswas, 2010) and certain projections indicate rice yield reductions in the near future (Adusumilli and Bhagya Laxmi, 2011) mainly due to growing water scarcity. Scientists have estimated that by 2025, 15-20 Mha of irrigated rice will suffer some degree of water scarcity (IRRI, 2013). Due to growing demand of water for non-agricultural uses, water availability of irrigation is continuously declining. Rice –wheat cropping system (CS) covering 10.3 Mha area is the major consumer of irrigation water with low water-use efficiency, particularly in the Indo-Gangetic plains of India (Tripathi, 1990).The sustainability of the rice-wheat system in the Indo-Gangetic Plains (IGP) is at risk owing to higher water requirement of the rice crop and the conventional production practices resulted in high cultivation cost and inefficient use of inputs. In the western Indo-Gangetic Plains (IGP) water is increasingly becoming scarce because agriculture is facing rising competition from the urban and industrial sectors (Toung and Bhuiyan, 1994). In many parts of the region, overexploitation and poor groundwater management has led to decreased water table and negative environmental impacts (Saharawat et al., 2010). Deterioration of land quality due to different forms of soil degradation and excess residue burning are other pervasive problems in the region (Bhattacharyya et al., 2013a; Das et al., 2013). These factors lead to consideration of conservation agriculture (CA) for better sustained productivity, profitability and soil quality (Kassam, 2011). This calls for identification of suitable cropping systems other than the rice-wheat under irrigated conditions in the region. Maize, cotton and pigeonpea are suitable alternative crops to rice in the *kharif* (rainy) season in north-western IGP because of their relatively low water requirement.

Conservation agriculture has the following four principles: (i) minimizing mechanical soil disturbance and seeding directly into untilled soil to improve soil organic matter (SOM) content and soil health; (ii) enhancing SOM using cover crops and/or crop residues (mainly residue retention). This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated pest management (IPM); (iii) diversification of crops in associations, sequences and rotations to enhance system resilience and (iv) controlled trafficking that lessen soil compaction (FAO, 2012). The CA technologies involving no- or minimum-tillage with direct seeding, and bed planting, innovations in residue management (mainly residue retention) to avoid straw burning and crop diversification. Bed planting generally saves irrigation water (Gathala et al., 2011), labour consumption without sacrificing crop productivity (Hobbs and Gupta, 2000; Ladha et al., 2009b). The permanent bed planting technique has been developed for production cost reduction and conservation of resources (Lichter et al., 2008). Permanent raised beds permit the maintenance of a permanent soil cover on the bed for greater rainwater capture and conservation (Govaerts et al., 2005, 2007). The advantages of permanent raised bed planting over conventional ZT (ZT with flat planting) are that it saves irrigation water and weeding and fertilization application practices are easily performed by trafficking in the furrow bottoms and the fertilizers can be banded through the surface residues reducing potential nutrient losses (Limnon-Ortega and Sayre, 2002). Past research suggests some advantages of broad beds over narrow beds in maize-wheat system. For example, Akbar (2007) reported that there was about 36% water saving for broad beds and about 10% for narrow beds compared to flat sowing and grain yield increased by 6% for wheat and 33% for maize in Pakistan. In both cases, the furrows act as pathways for drainage in excessive rain and conserve rainwater in dry spells (Astatke et al., 2002). However, there is a need for wider scale testing of these new technologies under diverse production systems for productivity and water efficiency as the CA technologies are site specific and therefore, their evaluations are important to have significant adoption (Ladha et al., 2009a). Again without the systems approach, planting a crop without tillage will have problems and the producer will likely fail, blaming no-till, not the lack of management (Hobbs and Gupta 2003). However, little research has been done to verify these benefits. Jalota et al. (2008) study the direct and interactive effects of date of sowing and tillage-plus-wheat residue management practices on growth and yield of cotton and wheat and to increase the profitability by reducing the tillage operations, which costs about 50% of the sowing cost. Yields were 23–39% higher in tillage treatments than minimum-tillage. In wheat, grain yield in tillage treatments were at par. Water productivity amongst the tillage treatments in cotton was 19–27% less in minimum tillage than others tillage treatments. Considering these facts, four experiments under conservation agriculture were conducted during 2011-12 and 2012-13 to explore the better alternatives to rice-wheat cropping system and also to device a better option within the rice-wheat cropping system for saving the irrigation water by investigating the impacts of CA technologies (ZT alone, ZT with residue retention and ZT with residue retention and bed planting) on the performance of a rice-wheat, cotton-wheat, pigeon pea-wheat and maize-wheat cropping systems in the western IGP.

II MATERIALS AND METHODS

(a) Experimental site

The experiments on rice-wheat, cotton-wheat, pigeon pea-wheat and maize-wheat cropping systems were conducted during 2011-12 and 2012-13 at the 14B block of research farm of the Indian Agricultural Research Institute (IARI), New Delhi with the treatments shown in Table 1 and 2. A uniformity trial on wheat was undertaken during *Rabi* 2009-10 so as to ensure uniform soil fertility in the entire field. The climate of the research farm is semi-arid with dry hot summer and cold winters. May and June are the hottest months with mean daily maximum temperature varying from 40 to 46° C, while January is the coldest month with mean daily minimum temperature ranging from 6 to 8° C. The mean annual rainfall is 710 mm, of which 80% is received during southwest monsoon from July to September and the rest is received through 'Western Disturbances' from December to February. Air remains dry during most part of a year. The mean wind velocity varies from 3.5 km hr^{-1} during October to 4.3 km/ hr in April. Pan evaporation varied between 3.5 to 13.5 mm d^{-1} and reference evapotranspiration from 9-15 mm/d. Mean daily values (during different weeks) of meteorological parameters recorded at the IARI meteorological observatory adjoining to the experimental site during the *kharif* and *rabi* seasons of 2012-13 are presented in Figs.1 (a) & 1(b). The soil texture of the site was sandy clay loam.

(b) Crop management and biophysical data recording

Bt-cotton hybrid 'Bollguard II Nikki', Pigeonpea 'Pusa 992' and Rice 'PRH 10' for nursery were sown by May-end each year and harvested in the second fortnight of November whereas Maize 'HQPM-1' and rice were sown in first week of July and harvested in November. Wheat cv. 'HD 2932' was sown by November-end using seed drill at 23 cm row spacing. A zero-till seed-cum-fertilizer drill was used for rice and wheat sowing on flat surface, while a bed planter was used for sowing under the raised-bed system. Recommended dose of fertilizers were applied in each crop. In the first year before the initiation of the experiment, wheat was harvested from the experimental plots and wheat residues were retained in the PBB + R or PNB + R plots. Wheat straw yield of 2009–2010 (the immediate past crop was 6.5 kg/ha. It was estimated that in all years, about 4.5% of wheat straw remained as stubble in the CT and other residue removal plots. Similarly, as stated earlier, about 40% of wheat straw was returned in the residue retention plots in cotton in all years. In the second year, wheat residues (40% of 6.5 kg/ha i.e. 2.6 kg/ha were retained in the newly introduced ZT+R plots. All herbicide applications and pest controls were done by using recommended practices. In addition, one manual weeding was also performed in all the crops at 40 days after sowing, while no manual weeding was required in wheat.

Straw weight was determined after oven-drying at 70^0C to a constant weight and expressed on an oven dry-weight basis. Yields of seed and grain as well as straw/stover were taken from the net plot area after discarding the border rows. In each treatment, there were 12 rows for narrow-beds and six rows for broad-beds. For cotton, pigeon pea and maize and narrow-beds (row to row spacing = 0.7 m), central four rows constituting 5 m length was harvested for yield measurement whereas, for wheat and for narrow -beds, four central beds with 3 wheat rows in each bed. For broad-beds, wheat yield measurements were taken from two central beds with 5 wheat rows in each bed. For ZT/CT plots (where conventional flat sowing was done), crops were harvested from an area of 2.8 m × 5.0 m for yield measurements. To express the overall impact of treatments in terms of comparable yield data, the entire grain and seed yield were converted into wheat equivalent yield (WEY) and then system productivity was determined by taking *kharif* and *rabi* crop as a system.

(c) Measurement of irrigation water, total water applied and water productivity

The irrigation water depth applied to each experimental plot was measured using a digital velocity meter and the wetted area of the field channel. At the starting of the experiment a rating curve was generated showing the relationship between flow depth and discharge in the main channel and then an exponential equation was developed. Afterwards every time at the time of irrigation only flow depth was measured in the channel and corresponding discharge was determined using either the rating curve or the exponential equation developed. Irrigation water depths indicated by the soil moisture deficit (SMD) in each treatment was calculated using soil moisture content before irrigation and root zone depth of plant besides bulk density using the Eq. 1 and time taken to fulfil the SMD.

$$SMD = (\theta_{Fc} - \theta_i) \times D_{RZ} \times B_d \quad (1)$$

where, SMD: soil moisture deficit (mm), θ_{Fc}: soil water content at field capacity (%), θ_i: soil water content before irrigation (%), D_{RZ}: root zone depth (mm), Bd: bulk density of soil (Mg m^{-3}). Soil moisture content at any time was measured by TDR (Time domain reflectometer), calibrated using gravimetric method. Daily rainfall data were collected from a rain gauge located at about 500-m away from the experimental plots. Effective rainfall was calculated using standard methods given by FAO and then total amount of water applied was computed as the sum of water applied through irrigations and effective rainfall. Water productivity (kg grains $ha^{-1}.mm^{-1}$ of water) was computed using equation 2 as given by Bhushan et al. (2007):

$$\text{Total water productivity} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total water applied (mm)}} \quad (2)$$

III RESULTS AND DISCUSSIONS

(a) Yield under different cropping systems

Based on the two years' mean data it was observed that wheat equivalent yield of rice-wheat system ranged from 6.51 to 8.35 t/ha. The highest wheat equivalent yield (WEY) was found in case of DSR with zero tillage and rice residue with moongbean residue whereas it was minimum in case of conventional transplanted. It was also observed that yield was more in case DSR with zero tillage and residue retention. Similarly from the first year, the plots under PBB + R with zero tillage had significantly higher cotton and pigeon pea compared with CT plots (farmers' practice), resulting in a higher system productivity (wheat equivalent yield; WEY). But in case of maize flat zero tillage with residue yielded more grain. WEY in case of cotton, pigeon pea and maize ranged from 11.71 to 14.78, 9.43 to 10.49 and 7.88 to 8.89 t/ha.

(b) Water productivity under different cropping systems

Total water applied in rice-wheat, cotton–wheat, pigeon pea-wheat and maize-wheat were shown in Table 2 and 3). It was observed that in both years total water applied were highest for the CT plots, whereas PBB + R plots received the least water in both years. Residue retention invariably reduced the amount of water applied in both years. There was irrigation water saving from 44 to 69%, total water saving from 35 to 58% and system water productivity increased from 91 to 171% (Table 4) in all the system compared to transplanted rice-wheat system. This shows the effectiveness of all the cropping systems tried and can be used as alternate cropping systems to replace rice-wheat cropping system in the region.

Similar results were found by Gathala et al. (2013) that zero-tillage direct-seeded rice (ZT-DSR) with residue retention and best management practices in north-western Indo-Gangetic Plains (IGP) provided equivalent or higher yield and 30–50% lower irrigation water use than those of farmer-managed puddled transplanted rice (CT-TPR). Similarly Hobbs and Gupta (2003) showed water savings of 30% due to the adoption of zero tillage in rice-wheat systems. Humphreys et al (2005) showed a 20% to 35% savings in irrigation water under zero tilled wheat compared to conventionally till in the rice-wheat belt of the Indo-Gangetic plains. Permanent raised beds demonstrated 13%, 36% and 50% higher grain yield, water saving and water productivity, respectively, for the wheat crop at Garden city, Kan (Hassan et al., 2005).

IV CONCLUSION

The major aim of this study was to evaluate the impacts of promising conservation agricultural practices on crop and water productivity and finding alternate cropping systems to replace rice-wheat system in the western IGP. Results indicated that permanent beds with residue addition (PBB + R plots) had a gain in the mean (of last two years) all wheat based cropping system in cotton and pigeon pea except maize, where in maize flat sown with zero tillage and residue reflected higher yield and water productivity. Among rice-wheat cropping system zero tillage with residue gave highest yield and water productivity. Thus, these results are of tremendous importance in terms of identification of a suitable sustainable management practice under a non-rice based cropping system and are very novel in the South Asia and showed the importance of conservation agriculture for saving the irrigation water.

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Table 1
Treatment details and plot design

Treatments	Treatment notations	Treatment description							
		Cotton, pigeonpea, Maize				Wheat			
		Tillage practice	Bed type	Residue retention	Row to row spacing; distance of the first row from the furrow (cm)	Tillage practice	Bed type	Residue retention	Row to row spacing; distance of the first row from the furrow (cm)
CT-Flat bed	CT-F	Conventional tillage	Flat beds	No	70	Conventional tillage	Flat beds	No	22.5
ZT-Narrow bed	ZT-NB	Zero tillage	Narrow bed (40 cm bed and 30 cm furrow)	No	70; 20	Zero tillage	Narrow bed (40 cm bed and 30 cm furrow)	No	13.0; 7.0
ZT-Narrow bed + residue	ZT-NB+R	Zero tillage	Narrow bed (40 cm bed and 30 cm furrow)	Yes; about 30% wheat residue	70; 20	Zero tillage	Narrow bed (40 cm bed and 30 cm furrow)	Yes; about 20% cotton residue	13.0; 7.0
ZT-Broad bed	ZT-BB	Zero tillage	Broad bed (100 cm bed and 40 cm furrow)	No	70; 15	Zero tillage	Broad bed (100 cm bed and 40 cm furrow)	No	21.5; 7.0
ZT-Broad bed + residue	ZT-BB+R	Zero tillage	Broad bed (100 cm bed and 40 cm furrow)	Yes; about 30% wheat residue	70; 15	Zero tillage	Broad bed (100 cm bed and 40 cm furrow)	Yes; about 20% cotton residue	21.5; 7.0
*ZT- Flat bed+residue	ZT-F+R	Zero tillage	Flat beds	Yes; about 30% wheat residue	70	Zero tillage	Flat beds	Yes; about 20% cotton residue	22.5
*ZT- Flat bed	ZT-F	Zero tillage	Flat beds	No	70	Zero tillage	Flat beds	No	22.5

*Introduced from the second year of the experiment.

Table 2
Impacts of tillage and residue management on water productivity (kg wheat grain/ha.mm) under the Rice-wheat system

Treatment	Mean of two years	
	Total water applied in the system (mm)	System water productivity (kg wheat grain/ha.mm)
DSR-ZTW	1592.34	6.26
DSR-ZTW+BM	1563.84	6.65
DSR-ZTW+RR	1558.34	6.41
DSR-ZTW-BM+RR	1545.34	6.82
DSR-ZTW-MR	1734.34	7.04
DSR-ZTW-MR+RR	1657.34	7.96
TPR-ZTW	2286.54	3.99
TPR-CTW	2279.54	3.99

Note: DSR- Dry seeded rice, ZTW- zero tillage with wheat, BM- brown manuring, RR- rice residue, MR- moogbean residue, CTW- conventional transplanted with wheat

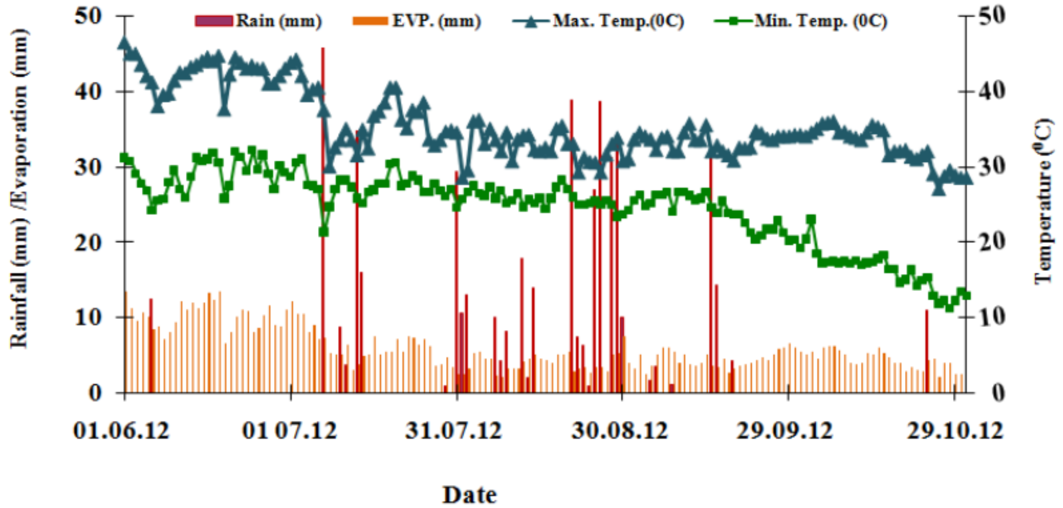
Table 3
Impacts of tillage, bed planting and residue management practices on water productivity (kg wheat grain/ha.mm) (mean of two years) under the different CA systems

Treatments	Cotton-wheat		Pigeon pea-wheat		Maize-wheat	
	Total water applied in the system (mm)	System water productivity	Total water applied in the system (mm)	System water productivity	Total water applied in the system (mm)	System water productivity
CT-F	1374	8.52	1153	8.17	1035	7.60
ZT-NB	1253	10.33	1080	8.86	940	8.16
ZT-NB+R	1232	11.24	1055	9.52	933	8.84
ZT-BB	1210	10.96	1027	9.73	913	8.96
ZT-BB+R	1176	12.58	1002	10.47	894	9.83
ZT-F+R	1280	11.14	1071	9.74	958	9.26
ZT-F	1349	10.13	1100	8.75	1029	8.13

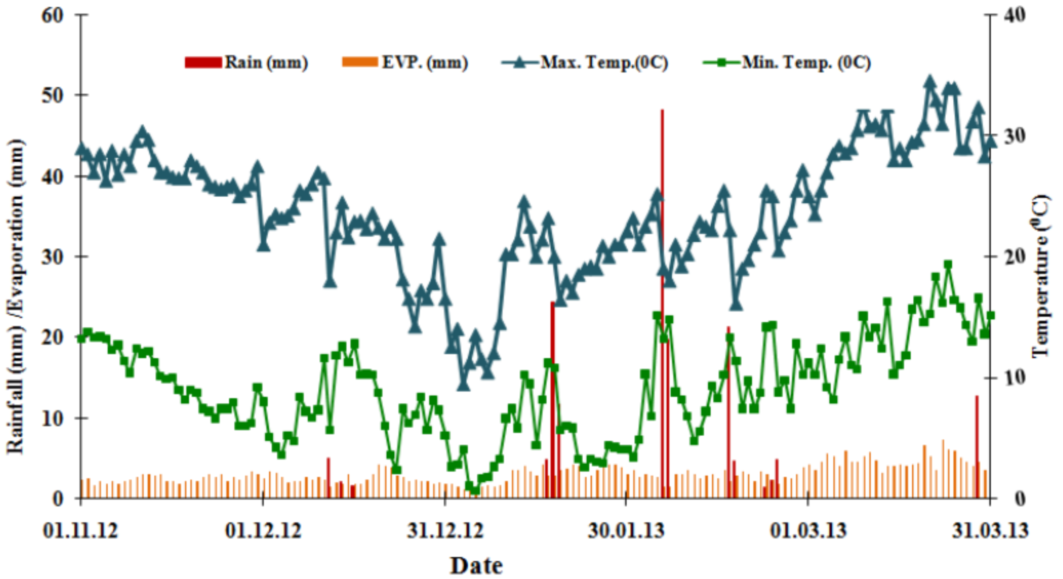
Table 4
Comparison of water savings under different cropping system in conservation agriculture (mean of 2011-12 and 2012-13)

Cropping system	Best Technology	% irrigation water saving	% total water saving	% increase SWP
Cotton-wheat	ZT+ Broad bed with residue	66.08	54.09	170.68
Pigeon pea -wheat	ZT+ Broad bed with residue	68.80	56.52	169.33
Maize-wheat	Flat zero tillage with residue	67.36	58.44	138.41

DSR-wheat	MBR-DSR-ZTW+RR+SMB)-wheat	43.61	35.18	90.81
TPR-wheat		-	-	-



(a)



(b)

Fig.1 Daily meteorological data of (a) *kharif* (1/06/12 to 31/10/12) and (b) *rabi* seasons (1/11/12 to 31/03/13)